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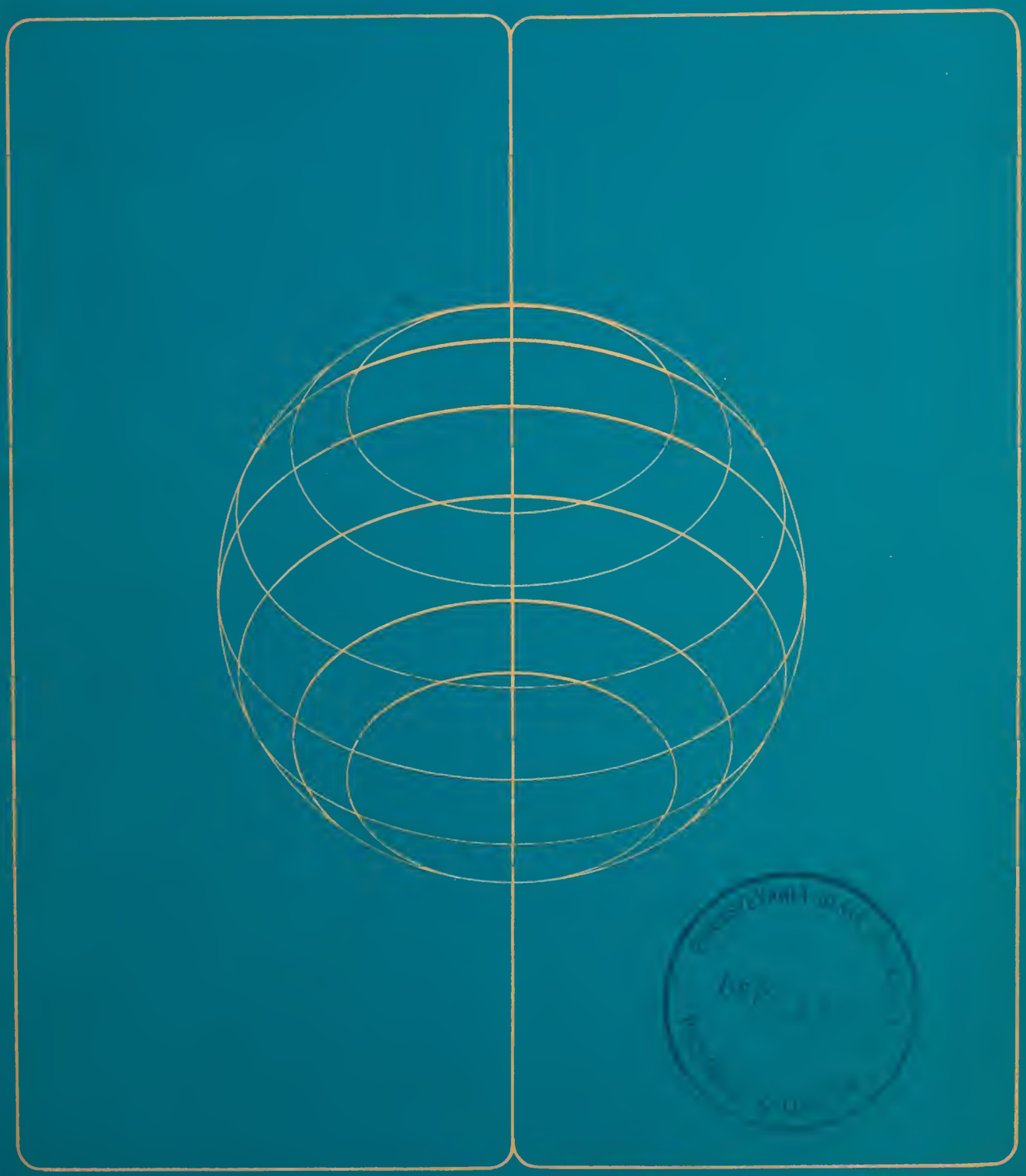
SCIENCE AND ENGINEERING



U.S. DEPARTMENT OF COMMERCE

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

essa

SCIENCE AND ENGINEERING

July 1, 1967 to June 30, 1969

U.S. DEPARTMENT OF COMMERCE
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Rocco C. Siciliano, Under Secretary
Myron Tribus, Assistant Secretary for Science and Technology
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Robert M. White, Administrator
Rockville, Md.
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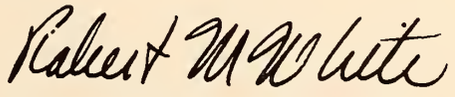
FOREWORD

The first *ESSA Science and Engineering* was published in 1968 and covered ESSA's progress from its July 13, 1965, beginning through June 30, 1967. The present publication is the second in this biennial *ESSA Science and Engineering* series and describes the course our work has taken over the two years from July 1, 1967, through June 30, 1969.

I hope that the descriptions of ESSA's work will indicate some of the ways in which the programs and services of our agency have matched the human and social needs that generate them. It is my hope also that this volume will serve as a means of disseminating information about our activities in a form useful to scientists, engineers, and all others who may be interested in the physical environmental sciences.



ROBERT M. WHITE, *Administrator*
Rockville, Maryland
June 26, 1970

PREFACE

The Environmental Science Services Administration's science and engineering programs during FY 68 and FY 69 are described in this publication. The first three chapters—Highlights, Organization and Program Areas, and Goals—provide a preview of ESSA's program activities for the reporting period, give details on the reorganizations within ESSA during the past two years and the program structure, and describe the goal areas through which research and development is utilized by ESSA to solve key problems involving the measurement, description, and prediction of the physical environment. Each of the other six remaining chapters deal with research and development activities within ESSA's service areas: Weather Forecasts and Warnings; Earth Description, Mapping, and Charting; Marine Description, Mapping, and Charting; Telecommunications and Space Services; Environmental Satellite Services; and Environment Data and Information Services. All of ESSA's science and engineering activities, including basic, applied, and developmental research, are incorporated in their relevant chapter. Data services for all ESSA programs, however, are discussed in a separate chapter rather than within the individual program areas; also included in this chapter is a discussion of ESSA's effort in scientific and technical communication.

All references made to organizations within ESSA refer to those structures as depicted in the organizational chart (Chapter 2) that have existed during the two fiscal years encompassed within this publication. Because of the changing nature of environmental science and technology, ESSA's organizational structure must remain dynamic in order to meet demands placed upon it for new services. Hence, additional organizational changes within ESSA will continue to occur in the future.

Production of a publication of this type is always a collective venture involving the cooperation of a number of individuals. Especially, I would like to thank Mr. John Bernick for editorial services; Mrs. Bertha Sladek for manuscript typing; Mr. Edward Koehler for production coordination; and Messrs. Max Chesy, William Welsh, James Schick, and Jack Rausch for graphic support. I am also indebted to Mr. Robert de Chancenotte and Mrs. BevAnne Ross of the American Meteorological Society for index preparation.

Jack N. Shuman

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Technical Information Specialist

CONTENTS

1 HIGHLIGHTS

Fields of interest involving the earth, its oceans, its atmosphere, and the space surrounding the earth are the concern of ESSA—Environmental Science Services Administration. ESSA is primarily an organization for providing service through its various components to other Government agencies and to the general public, but it also has the responsibility for initiating research related to environmental problems. Scientists and engineers of ESSA provide service and initiate research into the broad spectrum of environmental problems, ranging from earth-air and sea-air interactions to improved environmental prediction.

The first published review of ESSA's scientific and engineering accomplishments covered the period from July 13, 1965, through June 30, 1967. The accomplishments covering the reporting period from July 1, 1967, through June 30, 1969—Fiscal Years 1968 and 1969 (FY 68 and FY 69)—are the subject of this second publication.

Organization and Management

For the 4 years of its existence, ESSA has operated with the same basic organizational structure. However, a number of internal reorganizations have occurred. Two of the six major reorganizations during the reporting period of this publication were within ESSA Headquarters. The other reorganizations were within four of the five Major Line Components (MLC)—Weather Bureau, Coast and Geodetic Survey, National Environmental Satellite Center, Environmental Data Service, and Research Laboratories. Details of all reorganizations are found in Chapter 2. A complete discussion of the basic organizational structure of ESSA is in the first publication, *ESSA Science and Engineering—July 13, 1965 to June 30, 1967.*

The ESSA Headquarters staff had its first major reorganization on September 8, 1967. At that time, three Offices —Planning and Programs Evaluation, Science and Engineering, and User Affairs—were combined into a single Office of Plans and Programs, headed by an Assistant Administrator for Plans and Programs.

A second major Headquarters reorganization occurred on January 31, 1969. On that date, the Management Systems Division was created within the Office of Administration and Technical Services (ADTECH) from the merger of two Divisions—the Management and Organization Division and the Management Systems and Information Division.

The first reorganization by an MLC took place within the National Environmental Satellite Center (NESC) on September 22, 1967, with the activation of the Environmental Sciences Group (ESG). This Group has the responsibility to investigate the applicability of satellite observations to hydrology and oceanography within ESSA.

The MLCs had their second major reorganization on November 9, 1967. This reorgnization included the renaming and realining of the Institutes for Environmental Research (IER) into the Research Laboratories (RL). These Laboratories are comprised of 11 Laboratories, one Institute, and one Facility, with all units reporting to a single Director.

The MLC reorganization of April 5, 1968, within the Weather Bureau (WB) initiated a restructuring of the Bureau's field forecasting offices, with complete implementation occurring over a 5-year period. Once implemented, approximately 50 Weather Bureau Forecast Offices (WBFO) will be created. These WBFOs will receive forecast information output directly from the National Meteorological Center (NMC), the National Hurricane Center (NHC), and the National Severe Storms Forecast Center (NSSFC).

The establishment of the Office of Systems Development (OSD) within the Coast and Geodetic Survey (C&GS) on April 11, 1968, was the fourth MLC reorganization. This Office has the responsibility to design and develop systems which cross major C&GS program boundaries.

Selected Service Program Highlights

During this FY 68 and FY 69 reporting period, the various MLCs of ESSA significantly improved their service programs. Although additional information on programs covered generally in this chapter are found in Chapters 4 through 9, several programs are reported in detail only in this chapter. Selected highlights of these service programs follow for each MLC.

Weather Bureau

In response to a need accentuated by the worst flooding (August 1967) in the history of Fairbanks, Alaska, the Weather Bureau (WB) installed a telemetry system in FY 68 for the State of Alaska. The Bureau coordinated its effort with the Corps of Engineers and the Geological Survey. The system transmits hydrological information necessary to the preparation of flood warnings, using a specially designed radio network and associated telephone line-links to offices in Anchorage and Fairbanks where such information is collected and analyzed and where required warnings are issued.

The WB is continually improving its weather forecast techniques. During the past 2 years, an automated procedure for forecasting of maximum and minimum temperatures at the earth's surface was inaugurated at 131 cities in the country. Since September 1968, the NMC has transmitted these forecasts by teletypewriter twice daily directly from the computer to these cities.

To ensure more effective use of both radiosonde and rocketsonde data, better methods were developed for the construction of synoptic weather charts at high levels from 50,000 to 180,000 feet. High-level synoptic weather charts permit observers to follow the course of major stratospheric warmings which occur in the winter, to facilitate the research of stratosphere-troposphere interaction, and to improve the forecasting techniques at these high levels. These charts will be of value to the navigation of supersonic transports (SST) and are important to the determination of trajectories for experimental constant-level balloons and for reentries of space vehicles.

Another forecasting technique developed and tested successfully was a small-scale numerical model which permits forecasts of precipitation and surface winds in the eastern two-thirds of the conterminous States more rapidly than previously available computer guides. This subsynoptic advection model (SAM), placed in operation during FY 68, produces automated predictions and transmits them by teletypewriter twice a day for 79 cities.

The Systems Development Office (SDO) of the WB developed an analytical model for analyzing the performance of automatic weather-telephone briefing systems. This model will help overcome problems associated with the implementation of automatic weather-telephone systems. Classical multichannel queing theory was applied during model development to correlate relationships among service time (or message length), demand rate, available channel, and performance (probability of a busy signal).

Testing was successfully accomplished on an operational three-dimensional trajectory model developed by SDO. This model uses computer techniques to generate three-dimensional air trajectories from wind predictions produced by the six-level primitive equation (PE) model. Computerized 24-hour forecasts are produced from three trajectories and are then transmitted twice a day on the facsimile circuit from the NMC. Forecasts are displayed on a four-panel chart. Three panels consist of surface, 850-millibar, and 700-millibar temperature and dew point forecasts; the fourth panel contains 700-millibar relative humidity forecasts and 12-hour net vertical displacements of air parcels ending at 700 millibars. Computer forecasts are prepared by the NSSFC to improve tornado and severe local storms forecasts.

Coast and Geodetic Survey

The geodesy and photogrammetry projects of the Coast and Geodetic Survey (C&GS) involve studies ranging from crustal movements to geodetic satellite triangulation. Twenty-two special survey configuration sites across known faults of the San Andreas System of California were resurveyed to study crustal movement. Where feasible, the time term in each of the coordinates and elevations evolved from the repeat surveys was used to modify the collected data. Determination of such a time-varying model, from which rates of strain accumulation and other geophysical quantities can be computed over the entire area, may eventually be used to predict earthquakes.

Special releveling surveys were made in areas of subsidence such as the San Joaquin Valley of California. Major emphasis was placed on cooperative projects requested by many States and cities for urban geodetic control networks.

A cooperative agreement between the Department of Commerce (DOC) and the Department of Defense (DOD) enables the C&GS to provide technical direction and give considerable support to the worldwide geometric satellite triangulation program. Currently 16 BC–4 camera systems are available for the program, with the C&GS operating eight, assigning personnel to four, and having responsibility for the maintenance of all systems. ESSA, through its C&GS component, formulates the plans whereby ESSA can fulfill its responsibility for coordinating all Federal geodetic control survey functions.

In cooperation with the Geological Survey, the C&GS uses a recently developed system of computer-based techniques for analytical aerotriangulation to achieve results well within the established criteria for mapping control. Through additional planning and coordination of required mapping functions, this procedure can be as economical and efficient as geodetic methods for establishing mapping control.

The completion of the Worldwide Network of Standard Seismograph Stations was a major advance in seismology. This 115-station system is equipped with identical sets of ultrasensitive seismographs and related instrumentation to locate seismic activity more precisely. Records from this Network are gathered by and made into permanent files at the National Geophysical Data Center in Asheville, N.C.

Many new municipal ordinances require the placement of strong-motion instrumentation in tall buildings and earthquake-prone areas. To meet these requirements, the Seismological Field Survey of the C&GS has increased the size of its instrumentation network to 349 strong-motion stations and 368 seismoscopes by the end of reporting period. The record number of strong-motion seismograms obtained from the Imperial Valley of California earthquake of April

4, 1968, demonstrated the increased effectiveness of this expanded service.

Investigation of the November 9, 1968, earthquake in southern Illinois gave further evidence that local ground conditions have a pronounced influence on the intensity of shaking and demonstrated that continued research may improve methods for forecasting the effects of future and even more severe earthquakes. In accordance with a long-established C&GS policy, isoseismal maps are prepared following significant U.S. earthquakes; these maps have direct application in relating physical and environmental factors to industrial and urban development.

Successful results have been achieved with programs written for automated computation of geodetic bearings and distances, position determinations, and spherical triangulation determinations. Computer programs were prepared to complete the symbols dictionary portion of an automated cartographic process now under study. An 18-month contract was initiated to determine the feasibility of a computer-based system for automating the cartographic process.

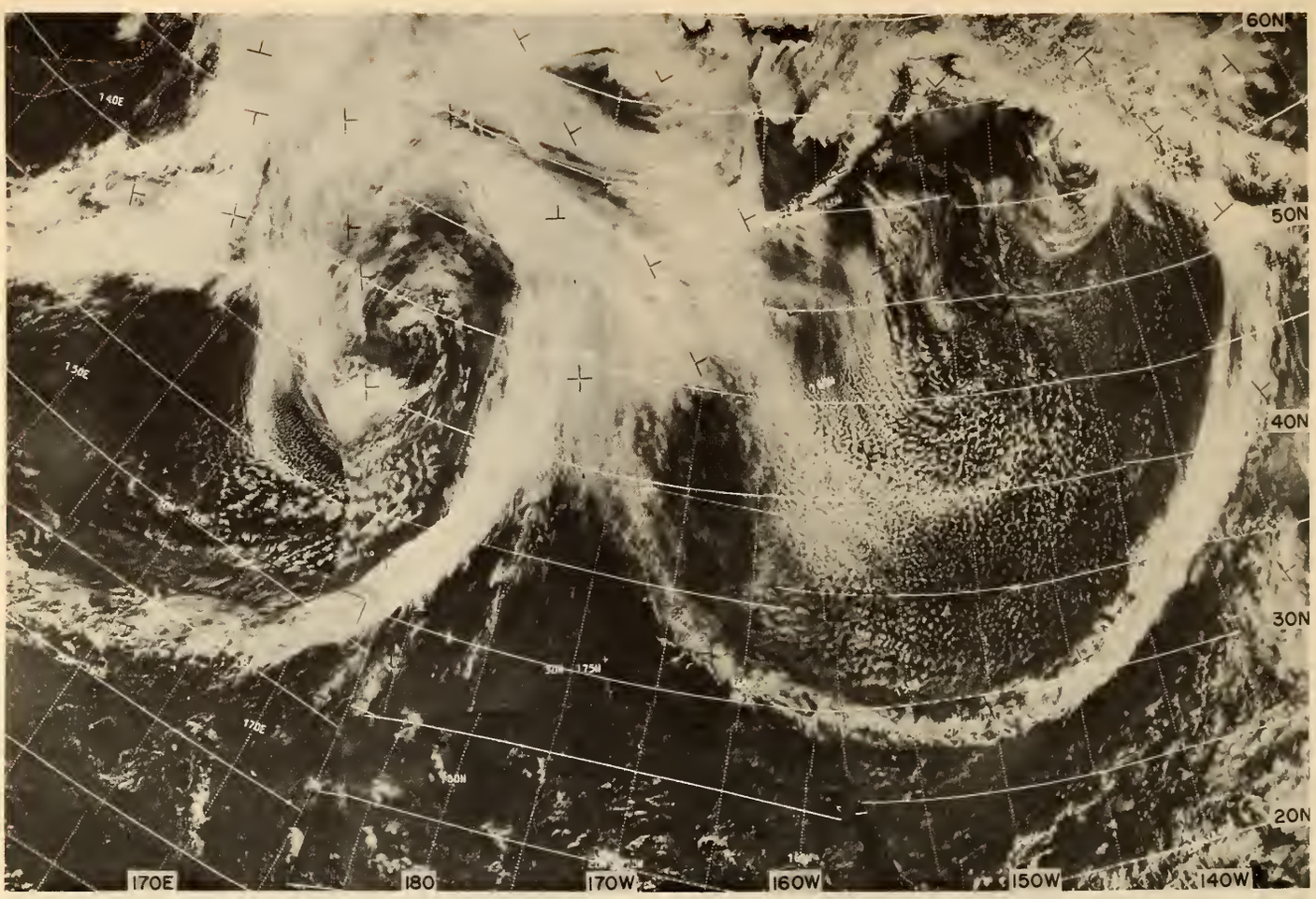
National Environmental Satellite Center

The most successful achievement of the National Environmental Satellite Center (NESC) in environmental satellites during the past 2 years was the unqualified success of the Satellite Infrared Spectrometer (SIRS) experiment on NASA's Nimbus 3 satellite. The SIRS, developed by NESC during a 10-year period and launched by NASA in April 1969, provides vertical temperature profiles along the satellite subtrack. The experiment involves use of radiance from seven channels clustered around the 15-micron carbon dioxide absorption region of the spectrum. Temperature profiles and geopotential heights of pressure surfaces are obtained on a global basis from approximately 100,000 feet downward to the surface of the earth in those regions having clear sky conditions and to cloud tops in those regions having cloudy sky conditions. Data processing conditions have been developed to derive temperatures and geopotential heights whenever the 120- by 120-nautical-mile field of view of SIRS is restricted by partly cloudy sky conditions; however, a number of problems remain. The NESC reduces SIRS data and provides them to the NMC for routine use in operational numerical analysis and prediction activities. Approximately 400 Northern Hemisphere SIRS soundings were available through June 1969 on a daily basis for use in the operational numerical analysis programs of the NMC. These SIRS soundings provide data over oceans or in sparsely populated regions where it is either impossible or impractical to use ground-based instruments.

The NESC reported that picture sequences from Applications Technology Satellites (ATS), used to measure cloud movements and related wind activity, yielded information in the following specific areas:

(1) Tropical air masses in long narrow jets that surge into the United States from the eastern Pacific tropics appear to accompany many U.S. tornadoes. The relationship

Launch of ESSA 9 spacecraft, February 26, 1969.



A mosaic map, produced from ESSA 9 spacecraft photographs taken at 0030 GMT on April 22, 1969, showing a strong extratropical cyclone system over the North Pacific Ocean.

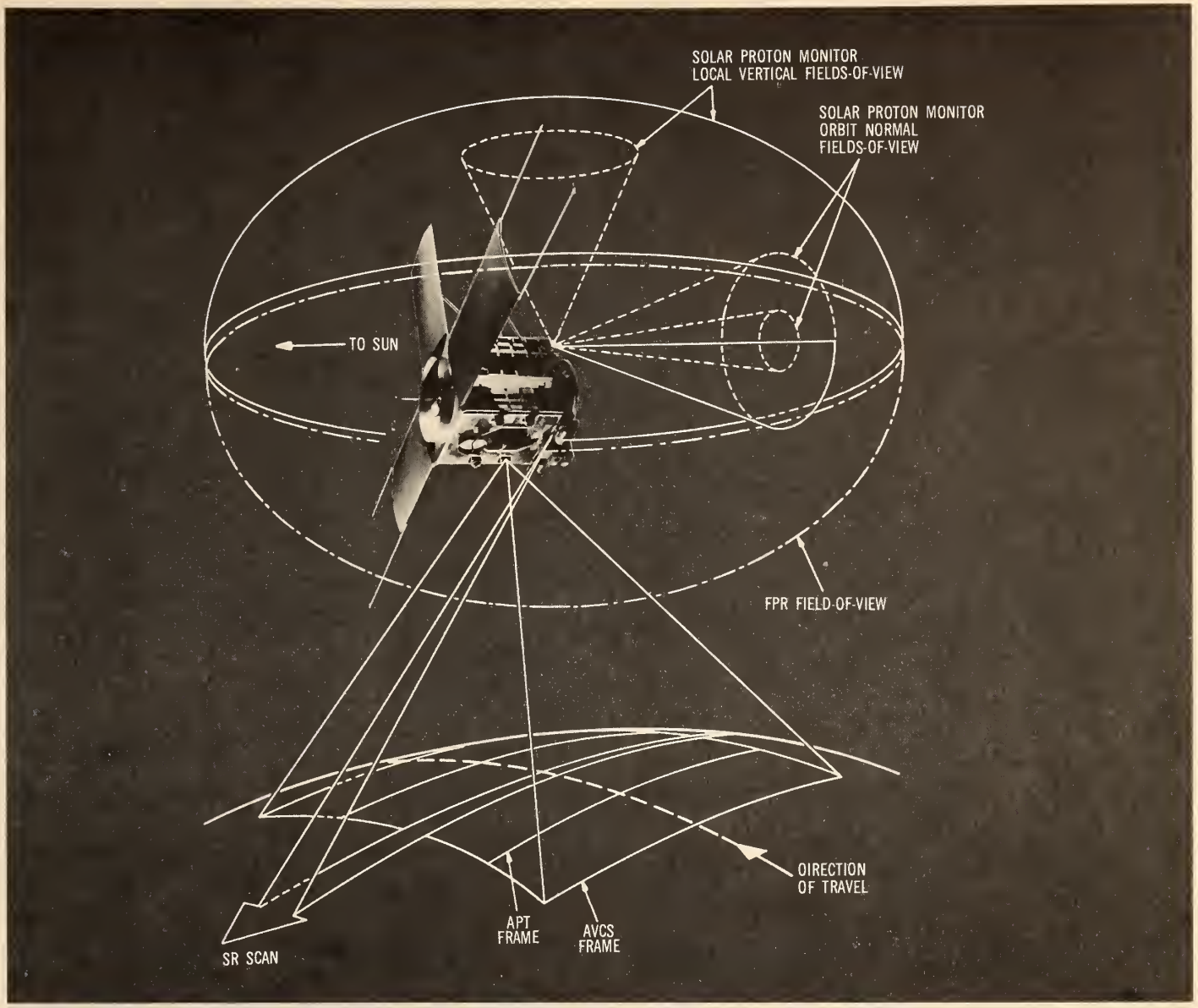
of these jet streams to severe storms will be studied as more data are gathered.

(2) Tropical hurricanes, the most destructive of storms that strike the United States, are also being investigated through ATS pictures made at 15-minute intervals. These pictures reveal changes in the structure of the spiral bands and the eye wall—the main energy region—which may be useful in efforts to modify these storms.

A high correlation has been observed between the average relative humidity present in the layer from the surface to 500 millibars and the amount, type, and pattern of clouds seen in satellite pictures. Based on this correlation, estimates of relative humidity throughout this layer are made from satellite pictures taken daily over the eastern North Pacific. These data are used daily at the NMC as additional input for the numerical weather analysis. Detailed humidity patterns, derived from satellite data obtained over the Pacific Ocean west of North America and over the Gulf of Mexico, are expected to improve precipitation forecasts for the United States. As ATS pictures become available regularly, these humidity estimates will be made over an area expanded to include all of the eastern North Pacific Ocean east of longitude 160° E.

During the winter and early spring seasons, data from the Environmental Survey Satellite (ESSA) spacecraft are used to provide information on the boundaries of snowfields and on the distribution of ice on the Great Lakes. Digited mosaics and pictures of snowfields are prepared daily for use in making flood potential estimates by River Forecast Centers (RFC) at Hartford, Conn., Kansas City, Mo., Portland, Oreg., Sacramento, Calif., and Salt Lake City, Utah. Charts showing ice conditions on the Great Lakes are also prepared and transmitted by facsimile for use by WBFOs at Cleveland, Ohio, and Detroit, Mich. The satellite pictures, and the charts and mosaics derived from them, provide the flood forecaster with a means, formerly unavailable, for maintaining current information on the areal extent of the snow cover. This information permits more accurate estimates of the water equivalent, and thus the flooding potential of the snowpack. The mapping of snow cover by complete mosaicking of satellite photographs was expanded to include Antarctic and Arctic regions in appropriate seasons.

During the last 2 years, the NESC launched three spacecraft (ESSA 7, 8, and 9) to maintain the National Operational Meteorological Satellite System (NOMSS) established in February 1966. These spacecraft are furnishing



Artist's conception and actual model of the TIROS-M meteorological spacecraft. Diagram courtesy of RCA Defense Electronics Products and photo courtesy of NASA.

worldwide pictorial coverage of the earth and its cloud systems daily, except in areas of polar night.

The TIROS-M (Television Infrared Observation Satellite), an operational prototype of the ITOS (Improved TIROS Operational Satellite) series, will add a nighttime cloud surveillance and day-and-night temperature mapping capability by means of a scanning radiometer. This prototype will combine functions now performed separately by two ESSA spacecraft, with a consequent cost savings resulting from fewer launches each year. The first launching is scheduled for January 1970.

Environmental Data Service

The Environmental Data Service (EDS), ESSA's archival arm, established an Agricultural Climatology Service Office (ACSO) in the Department of Agriculture (DOA) in February 1968. This new Office facilitates the real-time input of analyses of climatological data into decisions, operations, and policies of the DOA.

The EDS developed and tested a technique for using satellite data to provide climatological information about the total cloud cover. Variations in monthly averages of cloud amount, computed from data derived from the tropical Pacific Ocean, have a high correlation with changes in sea-surface temperature. These variations indicate the importance of sensible heat energy flux in the monthly averaged tropical circulation. In addition, the latitudinal gradient of biweekly averaged cloud top height, derived from satellite infrared data, was used to compute estimates of

diabatic heat energy involved with the Hadley circulation in the eastern Pacific tropics.

In May 1968, the first Environmental Data Processing System, managed jointly by the DOC (ESSA) and the DOD (Air Force), was dedicated. This new System complex, replacing separate computer systems, has about three times more capacity than the combined predecessor systems. The new complex is operated by EDS's National Weather Records Center (NWRC) and by the Air Force's Environmental Technical Applications Center (ETAC) through its Data Processing Division.

Research Laboratories

The Research Laboratories (RL) of ESSA operate several service programs in telecommunications, space disturbances, aeronomy and space data, and propagation conditions.

In July 1968, the Telecommunications Disturbance Forecast Center, operated for many years at Fort Belvoir, Va., by ESSA and its predecessors, was replaced by a real-time system which uses a timesharing computer to forecast the probability, time of occurrence, and duration and magnitude of shortwave fadeouts, polar cap absorption events, and magnetic storms and their effects on telecommunication systems. The new RL service, based in Boulder, Colo., permits users throughout the country to query the computer directly. The forecasting process utilizes solar, geophysical, ionospheric, and communication data from many sources. These data are then evaluated, placed in operating data files within the computer, and used to provide the communicator with relevant information and competent advice at any time.

The completion of the Global Solar Flare Patrol Network during the reporting period was an important service accomplishment in space disturbances. A new computer, installed at the Space Disturbance Forecast Center in Boulder to complement the Space Disturbances Monitoring Facility computer in Anchorage, automatically handled the analysis and transmission of solar activity data and warnings. Solar flare forecasts and warnings of routine and special nature were provided to some 70 primary users by teletypewriter or direct telephone line. Improved computerized techniques were developed to predict solar events for telecommunication and space programs and to provide procedures for predicting radiation at SST altitudes. A *Forecast Procedures and Techniques Manual* was published.

For aeronomy and space data, service programs provide data on ionospheric and tropospheric propagation, solar activity, airglow, aurora, and cosmic rays to support national and international needs. Approximately 1,500 requests for data—in the form of paper copies, microfilm, punched cards, magnetic tapes, and publication—are handled by the Aeronomy and Space Data Center each year; distribution of these data is made to other Federal agencies, universities, commercial laboratories, foreign institutions, and individuals. Expansion of automated systems for archival, retrieval, and publication of data continued. The responsibility for the Cornell University Visual Aurora Center was transferred to the Aeronomy and Space Data Center on July 1, 1968. Currently, all upper atmospheric geophysical disciplines except geomagnetism are now located in the Aeronomy and Space Data Center.

Service programs involving ionospheric predictions and data are prepared and disseminated for military, scientific, and engineering applications. A direct-access, timesharing computer has been introduced that is capable of providing forecasts of solar-geophysical disturbances which affect communications, surveillance, and the manned space effort. Tropospheric propagation predictions involve the development of physical and mathematical models for predicting the performance of tropospheric telecommunications.

Selected Research and Development Program Highlights

The research and development (R&D) programs of ESSA during the reporting period are categorized by disciplines or by project name. Additional information on programs mentioned briefly in this chapter are discussed more fully in Chapters 4 through 9, but some significant programs are reported in detail only in this chapter. Selected highlights of these R&D programs are presented below.

BOMEX Project

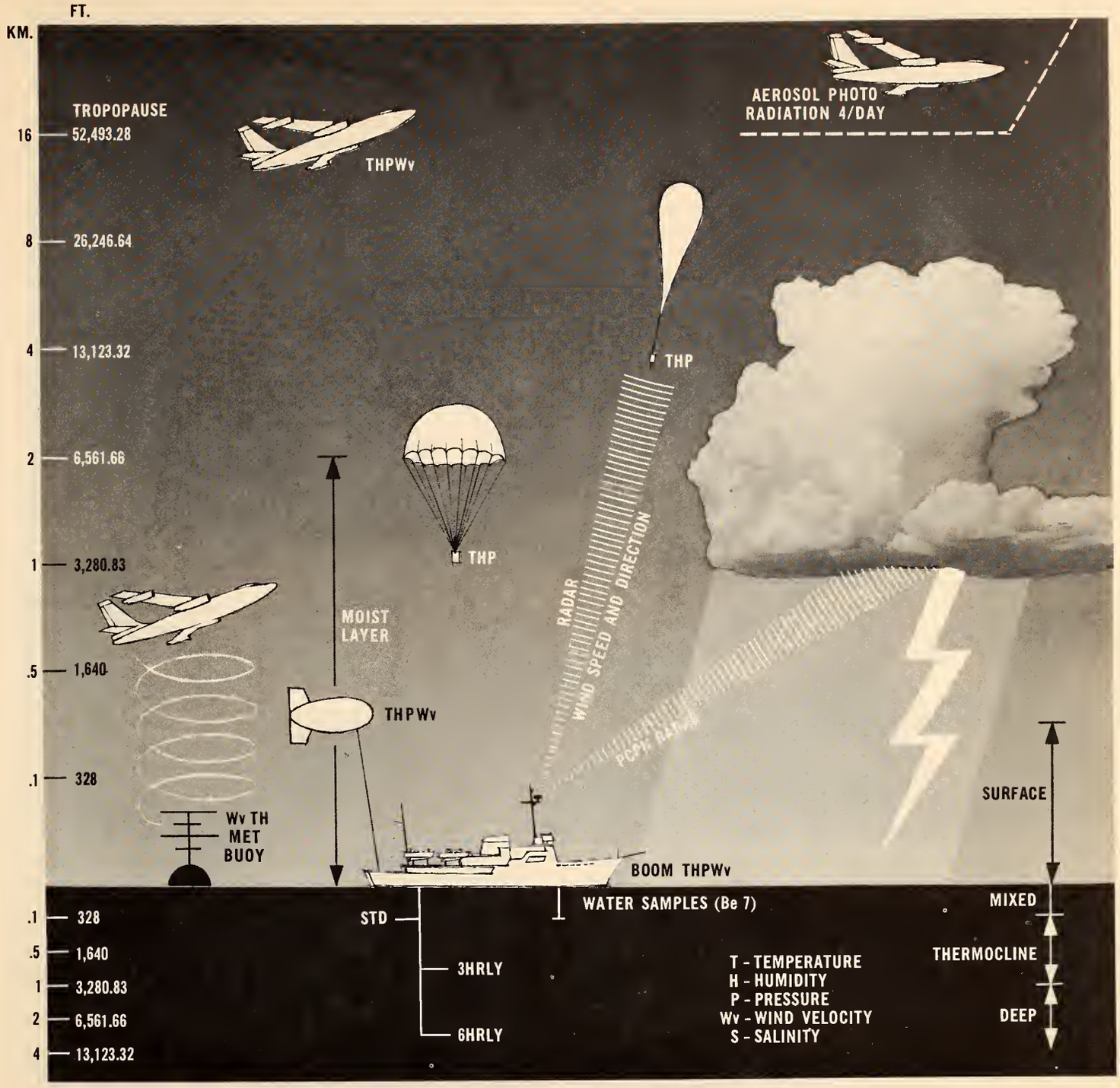
One of the most significant R&D efforts involving ESSA during the past 2 years was the Barbados Oceanographic and Meteorological Experiment (BOMEX). A bilateral agreement, signed on July 9, 1968, between the U.S. Government and the Government of Barbados inaugurated this international experiment.

The BOMEX project is a major contribution of the United States to the World Meteorological Organization's (WMO) World Weather Program. Management of BOMEX was assigned to ESSA's Office of World Weather Systems.

The project, recommended in the 1962 National Academy of Sciences (NAS)/National Research Council (NRC) *Report on the Interaction Between the Atmosphere and the Ocean*, Publication #983, was the first cooperative experiment in support of the international Global Atmospheric Research Program (GARP). This *Report* pointed out that a physical understanding of the processes of sea-air interaction is important because the atmosphere and the oceans, constituting the fluid portions of the earth, interact as one mechanical and thermodynamic system.

Initial planning for the BOMEX project was accomplished by the Joint Air/Sea Interaction Panel of the Interagency Committee on Oceanography and the Interdepartmental Committee on Atmospheric Sciences of the Federal Council on Science and Technology (FCST).

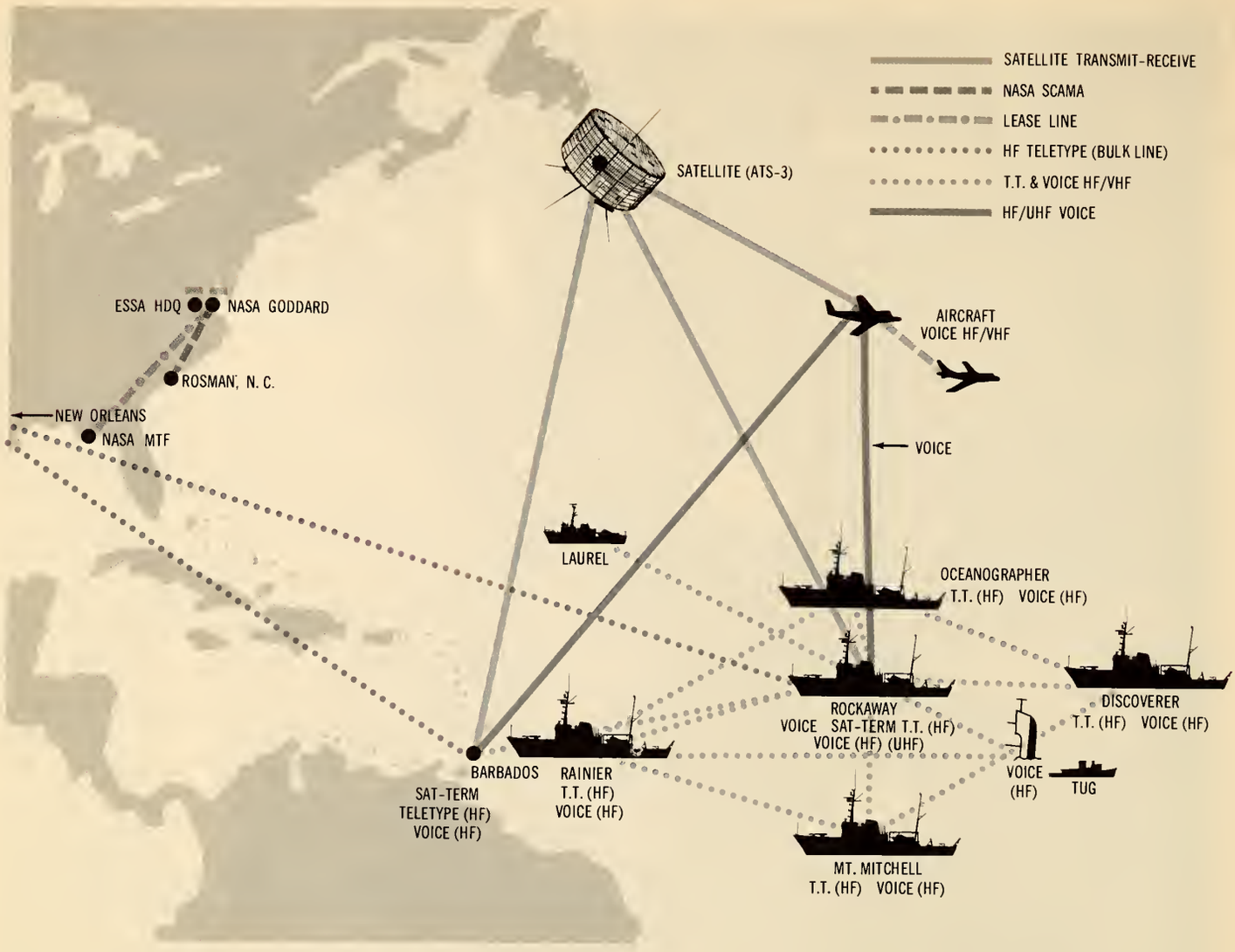
The scientific and practical significance of BOMEX is that an extension of the numerical forecast period beyond a few days must take into account the atmospheric energy sources to compensate for the known decay of atmospheric motions by friction. BOMEX was designed to obtain quantitative information on the energy sources and sinks over the tropics where much of the energy received by the earth in the



The BOMEX observation system.

form of shortwave solar radiation is stored in the upper layers of tropical oceans. The energy transfer at the sea-air interface to the atmospheric boundary layer in the tradewind zone was observed as part of the BOMEX sea-air interaction program, and the transfer of energy to the upper layers of the atmosphere was observed during the BOMEX tropical convection program. These two major experimental programs and other BOMEX scientific programs were highly successful in collecting the quantity and quality of observational data required.

The implementation of this national scientific effort was led by ESSA within the DOC, and included personnel from the DOD, Department of the Interior, Department of Transportation (DOT), Atomic Energy Commission (AEC), the NAS, National Aeronautics and Space Administration (NASA), National Center for Atmospheric Research (NCAR), and the National Science Foundation (NSF). The basic objectives of BOMEX are summarized in the phrase, "the joint behavior and interactions of the atmosphere-ocean system in subtropical and tropical waters."



The BOMEX communications network.

The experiment, which began May 1 and concluded July 28, 1969, was conducted in a 90,000-square mile area east of Barbados. Twelve vessels, 28 aircraft, and 1,500 scientists, technicians, and crew members from seven Government departments and independent agencies, 20 universities, and 12 private research activities participated in the experiment. The project was divided into four phases, each ranging from 15 to 19 days, during which the most intensive sampling of the atmosphere and ocean ever attempted was performed. Nearly 100 independent research projects were attempted. Over 2,400 upper air soundings, 1,400 ocean probes to depths of 1,000 meters, and more than 500 aircraft missions were planned. Thousands of observations were made, using a variety of sensor systems and platforms including satellites. Extensive scientific investigations were made of the sea-air interaction, tropical convection systems, radiation balance, oceanic circulation, and internal waves. These studies were initiated through the joint effort of Federal agencies, universities, and private laboratories and corporations.

The processing and scientific analysis of the data were initiated immediately following the field phase. The Barbados Oceanographic and Meteorological Analysis Project (BOMAP) was established within the RL of ESSA for this task. Personnel in BOMAP work in cooperation with other participating Federal agencies and nongovernmental laboratories. A major contribution to BOMAP is the data processing support provided by the NASA's Mississippi Test Facility at Bay Saint Louis, Miss. Scientific review and coordination of BOMEX and BOMAP with the objectives and planning activities of GARP have been accomplished by an advisory panel of the NAS under its U.S. Committee for GARP. Data will eventually be archived

at EDS's NWRC and at the National Oceanographic Data Center (NODC).

Meteorology

The various components in ESSA have made considerable progress in several major R&D programs. In weather modification, for example, numerical models were developed for: (1) the Great Lakes Program—to assess the potential of redistributing snow; (2) the Northeast Rain Augmentation Project—to study the physical feasibility of rainmaking from cyclonic storms; (3) the Florida Cumulus Seeding Program—to study the seeding potential for ice and condensation nuclei; and (4) the analysis phase of the Lightning Suppression Project—to study the electrical structure of thunderstorms. The numerical models provide a better understanding of the physics of these phenomena. When these Programs and Projects enter the field test phase, the models will assist in the analysis.

For weather forecasts and warnings research, the National Hurricane Research Laboratory (NHRL) has developed an improved statistical technique for predicting hurricane movement. The results reveal a 15-percent reduction in the average error for the 24-hour predicted position of the hurricane center.

A numerical model, which simulates many features of the evolution and decay of hurricanes and provides a better understanding of the physics and energy processes of hurricanes, has also been developed. This model provides data useful for study and improvement of the design of field experiments.

In addition, a numerical weather prediction model, developed for testing during the 1969 hurricane season, gives promise for more reliable prediction of hurricane movement and intensity where sufficient data are available for making the computations.

In weather analyses and forecasts research, a numerical SAM has been developed and operationally tested. This Model gives short-range (up to 18 hours) hourly circulation and precipitation forecasts for the eastern one-half of the conterminous United States. Results over a 1-year period show that these forecasts are superior to other numerical guidance available for the same period.

Sophisticated mathematical models of the atmosphere and ocean circulations were developed and employed in a number of important numerical experiments during FY 69, namely:

(1) Simulation of the January-February global climate was successful in accounting for the global rainfall distribution in defining the world desert patterns, delimiting the main river runoff basins, and predicting the location of spawning tropical cyclones. The key role of high and extensive mountain chains was reaffirmed.

(2) Extended prediction experiments were performed throughout the Southern Hemisphere and the tropics. These experiments indicate that the theoretical limit of atmospheric predictability to be at least 3 weeks and that several parameters previously thought essential for an initial description of the state of the atmosphere may be redundant. Also, the significance of large-scale sea-surface temperature anomalies on midlatitude circulation and of interhemispheric atmospheric coupling for forecast spans between 1 and 2 weeks was established.

(3) Definitive studies were completed on the atmospheric kinetic energy spectrum, derived from 10 years of data, and on the water balance over North America, the Gulf of Mexico, and the Caribbean Sea for a 5-year period.

(4) A generalized oceanic circulation model for basins with irregular bottom topography and side boundaries was completed. Calculations from this model, applied to a study of the circulation of the Indian Ocean, gave an excellent prediction of the variations of the ocean currents with the changing monsoons. An analytical study of the Gulf Stream explained many observed features of its meandering flow.

(5) Several extensive numerical simulations of thermal convection were performed, giving theoretical explanations for previously unexplained discrepancies between experimental and theoretical results.

Additionally, equations for 2-, 3-, 5-, 8-, and 12-hour predictions of cloud ceiling and visibility based on simplified surface weather parameters were developed and tested at selected major air terminals. Encouraging progress has been made in developing specialized techniques for predicting such rare events as very low ceilings which close an airport and in applying nonlinear models of physical and kinematic factors for improving ceiling and visibility forecasts.

The NMC's extended forecasts of the daily surface circulation during FY 69 has shown significant skill above persistence and chance to day 6 from the day of forecast. A series of experimental tests on every third forecast showed that use of long runs of the NMC 6-level PE numerical forecasting model should result in further improvement; the model is used to prepare special forecasts such as for national holidays, for space flights, and for springtime flood situations in the Mississippi Valley.

The WB scientists developed a method for tracking the earth-coordinate positions of meteorological sounding balloons by means of radio navigation aids (NAVAID) such as Loran-C—long range aid to navigation—and Omega. Preliminary results of feasibility experiments using Loran-C signals have demonstrated that upper air wind speed and direction can be measured with greater accuracy than by conventional means. Because this method does not require stabilization and precise position accuracy of the ground station antenna, it has potential use aboard moving ships.

To design and develop the next generation upper air observing measurement system, the SDO of the WB conducted an engineering study of atmospheric measurements and equipment. The objective was to provide functional specifications for which the required equipment would be developed. Many potential techniques, including satellite-borne sensors and ground-based indirect sensing, were identified and studied. A trade-off analysis revealed that a balloon-borne instrument package, using a NAVAID approach —Loran-C and Omega—for wind finding, was the most

cost-effective system for upper air observing measurements. After a critical review by the WB, this approach was unanimously accepted as "the next generation upper air observing system"; the SDO has been directed to proceed with its development.

The first prototype of an intermediate Automatic Meteorological Observing Station (AMOS) III-70 was completed and transferred to the WB's Test and Evaluation Laboratory (T&EL) for final tests. This Station will be a highly reliable and extremely flexible device, fabricated almost completely with integrated microelectronic circuits and designed to report such weather parameters as temperature, wind, pressure, and precipitation on long-line teletypewriter circuits.

Efforts in severe storm modification research have led to studies that give a better understanding of the life history of an individual storm, including such characteristics as the air flow through the storm, the development of the radar echo, and the hail and lightning associated with the storm. The feasibility of using airborne infrared techniques for the detection and quantitative analysis of hailstreaks has been established. A numerical method has been developed to analyze the electrical charge distribution in thunderstorms from aircraft measurements of the electrical field at cloud base. Stereophotogrammetric techniques have been developed for the quantitative study of cloud growth for possible future application to hail modification experiments.

In tropical cloud modification, field seeding experiment results compare closely with the numerical simulation of the seeding effect and reveal that massive seeding of a particular class of tropical cumulus causes more cloud development. Measurements from calibrated radar show that seeding has a significant influence on precipitation.

The first field seeding experiment directed toward the modification of Great Lakes snowstorms was accomplished in November and December 1968. Although the weather pattern during this period produced only two opportunities for testing the basic hypothesis, much information and experience were obtained about the mesoscale cloud systems over the Lakes, particularly in relation to: (1) target areas for seeding; (2) diffusion of the seeding agent and effect following airborne seeding at cloud base; and (3) radar analysis of artificial snow showers.

Hydrology

For river and flood forecasts and warnings, a cooperative research program was conducted at Danville, Vt., during the reporting period with the DOA's Agricultural Research Service. The objectives were to develop improved methods for measuring the water equivalent of the snowpack and techniques for computing the rate of snowmelt from meteorological factors.

Substantial progress was made in correlating the intensity of radar echoes with thunderstorm rainfall and in devising a method whereby a small number of real-time rain gage measurements can be used to check or calibrate the radar depiction of precipitation over a large area. Development of a prototype flash-flood warning device was completed and given field tests and evaluation by the WB.

Seismology

Seismological research was conducted in three broad categories: engineering seismology, seismic wave travel times and earth structure, and tsunami generation. Engineering seismology research included studies of seismicity and earthquake probability, amplification of seismic waves passing through low-density materials, and earth tilt in tectonically active areas. Seismic wave travel times through the earth structure—crust, mantle, and core—have been studied. Tsunami-generation studies have been directed toward identifying parameters of earthquakes associated with tsunamis.

Research in engineering seismology seeks to use knowledge of earthquake frequency and resulting damage to provide earthquake-resistance design criteria and seismic factors for both the private and public sectors of the economy. Through a reimbursable agreement, initially contracted in June 1966 with ESSA, the Department of Housing and Urban Development (HUD) provides a large portion of funds necessary for studying seismicity and earthquake probability. In response to HUD's request for earthquake loss data, a new technique was developed to estimate probable losses to dwellings in California resulting from (1) a maximum credible earthquake, and (2) a series of earthquakes likely to occur in California during a 100-year period. The results of a study involving the new technique indicate that dwelling losses would amount to approximately $1.2 billion if a great earthquake occurred in the San Francisco area, and that dwelling losses in California over a 100-year period from earthquake damage would total about $6.5 billion. The method developed for the estimation of dwelling losses in California is very general, and could be applied as a method to compute losses to structures other than dwellings and in areas other than California.

Another part of the HUD study has been the organization of all useful historical seismicity data for the United States to achieve rapid retrieval for statistical and other seismic studies. This seismic data consisting of data from 1938 to 1966 for approximately 28,000 earthquakes is listed on punched cards and magnetic tapes.

A major development during 1969 was the release of an interim seismic risk map for the conterminous States. The map indicates the maximum level of earthquake intensity likely to be experienced in any geographic area. In the paper that accompanies the map, tables are given which permit the estimation of the approximate frequency of occurrence of various levels of earthquake intensity throughout the country.

A system has also been developed which will highly automate the collection of earthquake intensity data throughout the United States. This new highly automated system will result in better coverage and reporting of earthquake damage, and will speed the dissemination of reports giving intensity data collected throughout the country.

An important area of study in engineering seismology is the response of surficial geology and soils to earthquake-induced vibrations. Structural damage resulting from vibrations is commonly more severe in buildings located on poorly consolidated or water-saturated materials than on hard rock. One of the prime goals of engineering seismology is to evaluate the potential hazard that vibration damage causes to various types of foundation materials. The C&GS approach generally has been to record data from both small earthquakes and microseisms simultaneously on various foundation materials, compute the Fourier amplitude spectrum of each seismogram, and then compare the spectra. The technique of using "microtremor" measurements has been adapted by the C&GS from the Japanese.

The preliminary field investigation by the C&GS of the Venezuelan earthquake of July 29, 1967, strongly suggested that a close relationship exists between severe earthquake-induced building damage and certain kinds of surficial geology in the Caracas Valley. Through a reimbursable agreement with the AEC, a study was initiated to examine the relationship between damage patterns and the underlying soil and rock types in Caracas. The initial field measurement portion of the study consisted of seismic measurements of small earthquakes and background noise throughout the Caracas Valley. Relative amplitudes of seismic waves recorded at various locations throughout the Valley were then compared with the physical parameters of soils and rock formation at each measurement site.

Studies of seismic wave travel times and the earth's inner structure have led to corrections for *P* (primary or compression wave) and *S* (secondary or shear wave) travel times, using data derived from 31 deep-focus shocks near Japan.

Corrections were made to the Jeffreys-Bullen surface travel time tables, with acceptable small standard errors, at 10 distances from the epicenter. The tables will be further refined by adding station corrections. These new travel time tables will be the standard for the next several years.

Observations of such identifiable events as fault creep, under investigation at a number of sites on the San Andreas and Hayward Faults in California, reveal that these events do not occur simultaneously at points tens of kilometers apart, but that conditions cause the creep to propagate along the fault at very low speeds. These observation results bear directly on the search for methods of earthquake prediction.

Earth strains in the vicinity of a large underground nuclear explosion were successfully measured to evaluate the possibility that a nuclear blast could trigger a large earthquake at some distance from the explosion. Steplike residual strains were reported after a nuclear blast and agree with those reported for earthquakes of the same magnitude. Earthquake strain steps do not decay within several days, if at all, but such strain steps from a nuclear explosion apparently decay to near zero within one-half hour. This decay with time appears to reflect the pressure history of the cavity, and may provide a way of distinguishing underground nuclear explosions from natural earthquakes.

First-motion studies of deep- and intermediate-depth earthquakes were investigated on a worldwide basis to study the distribution of stress within descending "plates" of earth's crust. (According to the plate theory, the earth's crust appears to be divided into six major plates which are moving with respect to each other.) Results show that plates of crust sink into the upper mantle as a result of forces exerted on the excess mass within the crust. Data on focal mechanisms, obtained from a regional study of the largest earthquakes occurring in western South America during the 7-year interval, 1962–68, indicate that the data are in overall agreement with an east-east northeast direction of underthrust for the Pacific crustal plate beneath the continent of South America.

Systematized isoseismal information from 55 earthquakes occurring between 1928 and 1967 and empirical formulas have been developed from these events to determine the radius of each grade of intensity for earthquakes of given maximum intensities.

A program is currently underway to identify significant parameters of earthquakes that are related to the generation of destructive tsunamis. Very crude relationships between tsunami wave height and earthquake magnitude, focal depth, and water depth in the earthquake epicentral region have been known for some time. Attempts are being made to improve these known relationships and to develop a relationship between the nature of earthquake focal mechanism and tsunami generation. The basic attempt is to identify particular types of focal mechanisms that result in tsunami generation. Current research emphasis is upon development of statistical criteria for the objective evaluation of the reliability of the focal mechanism computed.

Geodesy

Large-scale operational computer programs for satellite orbit prediction support the C&GS geometric geodesy program. Other orbit programs are being developed for geodetic and geophysical analysis of dynamical data. An analysis is underway of gravitational harmonics which have resonant effects on the Passive Geodetic Explorer Satellite (PAGEOS). An alternate representation of the earth's gravitational field, using surface layers of variable density instead of spherical harmonics, is being investigated.

Mathematical Geodesy, a major treatise by the late Martin Hotine, completed during the reporting period, will be published in October 1969 as *ESSA Monograph 2*. This publication updates the mathematical theory of geodesy based on the application of tensor calculus.

Geomagnetism

A reliable analytical method for deriving long-term secular change in the strength and direction of the earth's magnetic field was developed for application upon U.S. and world magnetic charts compiled for issuance beginning in 1970. This new method eliminates handdrawn graphics

and results in complete automation through the use of electronic computers and automatic plotters. The magnetic charts serve as the source of magnetic compass information included on all navigation charts.

The C&GS model—a Fortran IV computer program—of an International Geomagnetic Reference Field (IGRF) contributed to the final IGRF adopted by the International Association of Geomagnetism and Aeronomy (IAGA). The IGRF provides a universal reference field used by space scientists and by geophysical exploration groups as an acceptable datum for delimiting magnetic anomalies resulting from crustal and upper mantle structures.

Examples have been found of magnetic events preceding by 1 day the occurrence of earth creep on the San Andreas Fault in California. Interpretation of this type of magnetic event may offer a means for predicting earthquakes.

Trends in the earth's magnetic field offer clues to future developments. Should a field reversal develop, the shielding effect would be degraded, allowing greater penetration of solar radiation which may produce an adverse biological effect. To predict future magnetic developments, the Earth Sciences Laboratories (ESL) have analyzed one of the most recent field reversals and initiated the design and construction of required equipment to study such developments.

Spherical harmonic analyses were performed on the magnetic field of the earth for epochs 1725, 1760, and 1800, giving secular change of the field during historic times. The addition of these results with other analyses of later epochs will improve knowledge of the fluid motions in the earth's core and their relation to changes in the earth's magnetic field, and will determine whether the earth's field is beginning to reverse. Paleomagnetic facilities are now available to study details of the last reversal for comparison with present trends.

Charting

Past research in aeronautical charting on color process printing has resulted in the elimination of one five-color press run for each visual aeronautical chart produced.

Programs of research within marine description, mapping, and charting have resulted in the development of an automated method for predicting sea and swell for both the North Atlantic and North Pacific Oceans up to 36 hours in advance. This method, based upon wind forecasts of the numerical prediction models, was given operational testing during the reporting period.

Oceanography

The modification processes which a relatively dry continental air mass undergoes while moving over an ocean surface were investigated off the Virginia coast. Ships, tethered balloons, constant-level balloons, radar-tracking rawinsondes, and oceanographic observations were used to define the air mass-water modification processes. An intensive investigation of the developing southwestern monsoon moist layer was made from the Somali Coast of Africa to Bombay, India, utilizing level-tethered soundings, Boundary Layer Instrument Package (BLIP) radiosondes, salinity-temperature-depth (STD) recorders in position, Expendable Bathythermographs (XBT), and ATS satellite data. These field projects in sea-air interaction studies are providing preliminary information on exchange processes before a large-scale intensive study of the area is made.

The first operational test of a Tidal Current System (TICUS) of four to six buoys, each supporting subsurface current meters to measure speed and direction of tidal currents at three selective depths, was made during the tidal current survey of Long Island, N.Y. This new C&GS system complements the newly developed ODESSA (Ocean Data Environmental Science Services Acquisition) buoy system for measuring currents, salinity, and temperature in major bays, estuaries, and over the Continental Shelf.

A novel data systems design was developed to provide an integrated approach so that Ocean Survey Vessels (OSV) can accomplish both required ship-operations and scientific data activities. This data systems design embraces data acquisition, verification, editing, processing, and display and makes possible handling of large volumes of data per unit of time. The systems design also enhances substantially the effectiveness of OSV to collect subsurface, bottom, and sub-bottom marine data required by the scientific community and industry.

As part of a long-range Continental Shelf mapping program, portions of the northern Bering Sea floor were surveyed during the summer of 1968 by the USC&GS ships *Surveyor* and *Oceanographer* and during the summer of 1969 by the *Surveyor*. Data were collected on bathymetry, gravity, magnetism, sediments, currents, and tides for use in the preparation of maps showing bathymetry, gravity, and magnetism of the area. This survey and scientific interpretation of collected data are a cooperative effort of ESSA and Geological Survey scientists who are interested in the structure and composition of this large basin.

A highly sophisticated model of the sea-air system was developed during the past 2 years. An analysis of two preliminary experiments indicated that important features of surface hydrology, such as the formation of a desert in the tropical rain belt, can be successfully simulated and applied to the study of climate evolution, to the development of very long-range predictions, and to the analysis of the effect of weather modifications.

In March 1967, the USC&GS ship *Oceanographer* began its global expedition from Jacksonville, Fla. The ship visited Great Britain, Monaco, the Soviet Union, Ethiopia, India, Malaysia, Australia, New Zealand, Chile, and Peru before reaching Seattle, Wash., in December. During the various "legs" of its journey, the ship accommodated more than 150 marine scientists, the majority representing various countries in the world. The ship's scientists did considerable research in physical oceanography, marine geology and geophysics, bathymetry, and sea-air interaction.

Telecommunications

Several new telecommunications and space developments have taken place in millimeter-length wave propagation. These developments include a climatological method for predicting radio absorption by clouds and precipitation and a method for estimating maximum thunderstorm absorption; both methods will be used in communication systems designs. Research in radio meteorology has led to (1) development of a combined optical-radio method for determining average water vapor content of air along a path and for averaging evaporation from the underlying surfaces, and (2) determination of meteorological factors causing extended circuit outages along an obstacle diffraction path.

A technique has been developed which allows for laboratory experimentation on the performance of high frequency (HF) radio channels by simulating the propagation characteristics and effects of atmospheric radio noise, permitting communication equipment tests in the laboratory, and minimizing the need for expensive field tests.

In the field of optical wave propagation, a prototype two-color geodetic distance-measuring instrument has been developed. Field testing has demonstrated a precision surpassing any of the presently available commercial instruments and providing a greater potential for geodetic survey operation economies.

A study confirmed the theory that very low frequency (VLF) energy, less than 1.5 MegaHertz, is transmitted along magnetic field lines at great heights. Because solar outburst events greatly attenuate VLF signals, a study was also made to calculate the effects of these events on VLF propagation. Both of these studies will aid in describing and predicting the propagation of VLF signals.

Studies also have been conducted on the irregularities of the ionosphere and exosphere, using signals from satellites. These studies have permitted precise measurements of the electron density along the satellite path, and provided correlation of electron density peaks and troughs at high latitudes with other phenomena and ionization irregularities from Explorer 20 and Alouette I and II satellite data. By using data from these two series of satellite flights, measurements of the mutual impedence between two electrodes can determine the electron density accurately.

Laboratory measurements of the reaction rates among ionized and neutral constituents found in the upper atmosphere have provided valuable basic physical data for understanding the behavior of ionization during space vehicle reentry. Other studies conducted provide strong evidence that the observed water cluster ions in the upper atmosphere cannot be entirely explained as rocket contamination, an implication important to understanding the chemistry of the D-region of the ionosphere.

In space disturbances forecasting research, a ground-based solar proton detection system and improved prediction techniques for solar flare and polar cap absorption events have been developed.

Satellites

NASA's ATS–1 and ATS–3 spacecraft, launched in December 1966 and November 1967, respectively, each carry two experimental systems important to the development of ESSA's environmental satellite system. The first of these systems is the spin-scan cloud-camera (SSCC) system. The ATS–1 carries a SSCC capable of taking a large-area photograph over the earth every 24 minutes, or alternately every 15 minutes if only one-half of the image is desired. The ATS–3 carries a similar SSCC system; initially this camera system had full color capability, but a failure of the red-sensitive channel reduced the effective imaging to black-and-white. The SSCC pictures have been used to study the development of the tropical storm systems and severe local storms. Techniques were developed for using the picture sequences to obtain realistic estimates of upper level winds, particularly over data sparse areas.

The second experimental system carried on the ATS spacecraft involved the testing of several systems for collection, transmission, and retransmission of raw and processed data. Automatic stage indicators were queried by the satellite at specified intervals, and their data were then acquired by the satellite and retransmitted through its Transponder System to a central collection point. Processed satellite photographs, analyzed charts, and time signals were sent from originating ground stations for relay to remote-receiving stations.

The success of these two experimental systems forms a firm basis for the development and deployment of the Geostationary Operational Environmental Satellite (GOES) system. The first prototype of the GOES spacecraft, NASA's Synchronous Meteorological Satellite (SMS), will be launched in 1972 according to current plans.

The SIRS on board the Nimbus 3 satellite was developed, tested, and qualified by the NESC with the fiscal support of the NASA. The SIRS instrument was spectacularly successful and was still operational at the end of the reporting period. The SIRS represents a major scientific breakthrough of paramount importance to meteorology. It is now scientifically possible and economically feasible to obtain routinely on a global basis quantitative values of the vertical profiles of temperature and corresponding geopotential heights of pressure surfaces vital to improved numerical analysis.

Follow-on models of SIRS, incorporating a smaller field of view and scanning normal to the satellite subtrack to improve accuracy, to increase area coverage, and to enhance the probability of obtaining clear sky conditions, will be flown on future Nimbus spacecraft. The SIRS-B, an instrument similar to the first SIRS but with added capability for obtaining measurements of the vertical distribution of moisture in the atmosphere, will be tested aboard Nimbus D which is scheduled for launch during 1970. Two additional instruments are being designed to acquire vertical temperature and moisture profiles from satellites: the Infrared Temperature Profile Radiometer (ITPR) and the

Vertical Temperature Profile Radiometer (VTPR). The ITPR is intended to provide an improved capability for acquiring data over partly cloudy areas; the VTPR is designed as a relatively small instrument package for use on operational spacecraft beginning in 1972. An operational system which will also provide gross moisture profiles is planned for ESSA's ITOS spacecraft in 1972.

Design has been completed and fabrication is about one-half completed on a television scan-display for analysis of ATS-derived cloud motions. A computer program has been written and checked to use outputs from this device. The principle of this scan-display system is (1) to assemble a picture sequence into a time-lapse display by electronic storage and display, and (2) to enable the operator to produce punched paper tape data for a digital computer which will make maps of cloud motion. The purpose of the system is to automate procedures for deriving useful wind data from the ATS, and later from the GOES on a more accurate and timely basis.

A program for estimating high-level tropical winds from cirrus plumes seen in satellite pictures is now in daily operational use. These derived winds provide the primary source of data for the daily tropical analyses and forecasts produced by numerical methods. With the inclusion of wind data from satellites, much improved analyses (and hence forecasts) are possible for the entire tropical and subtropical climatic belts. A better understanding and more effective surveillance of tropical weather events are valuable, not only for immediate use, but also for studying the relationship between tropical and midlatitude weather processes.

There have been promising developments in the use of High Resolution Infrared Radiometer (HRIR) data from satellites to measure sea-surface temperature. Although the validity of some random detail apparent in the analyses must be checked, major features such as the west wall of the Gulf Stream are clearly defined. Preliminary results show that horizontal gradients of absolute temperature appear to be within usable limits of accuracy.

Cloud pictures are required for the development of an objective method to derive constant pressure heights for numerical models of the atmosphere. Vertical motion is indicated by the presence or absence of clouds; this motion indicates vorticity—or the rate at which air spins with respect to the earth. To attain a corrected current forecast analysis, vorticity values are used as the basis for modifications to the previous 12-hour forecast map contours. The current procedure, which is still under development, is primarily manual, but work is progressing toward a fully automated technique. Developments of this kind hopefully will result in greatly improved analyses over oceans and other sparse data areas, and hence to improved forecasts.

2 ORGANIZATION AND PROGRAM AREAS

The mission responsibility of ESSA, broadly stated, covers the description, study, and prediction of the physical environment. It is the responsibility of ESSA to collect and interpret environmental data, using such data to obtain a basic understanding of the nature and behavior of man's environment, to predict and give timely warnings of environmental hazards, and to facilitate engineering decisions in building design and urban planning. ESSA also conducts R&D to achieve an understanding of the processes and phenomena of the physical environment and to improve the capability to discharge its mission.

This mission is administered through eight substantive "service" activities subdivided into program elements for planning, programming, and budgeting. These service activities are fulfilled through ESSA's five Major Line Components (MLC): the Weather Bureau (WB), Coast and Geodetic Survey (C&GS), Environmental Data Service (EDS), National Environmental Satellite Center (NESC), and Research Laboratories (RL).

Organization

During this reporting period ESSA made certain modifications to its internal structure, although the basic organizational structure for the MLCs established in 1965 was retained. Five major organizational changes occurred within the ESSA program management structure, two within ESSA Headquarters and three within the MLCs—one each for the RL, WB, and C&GS.

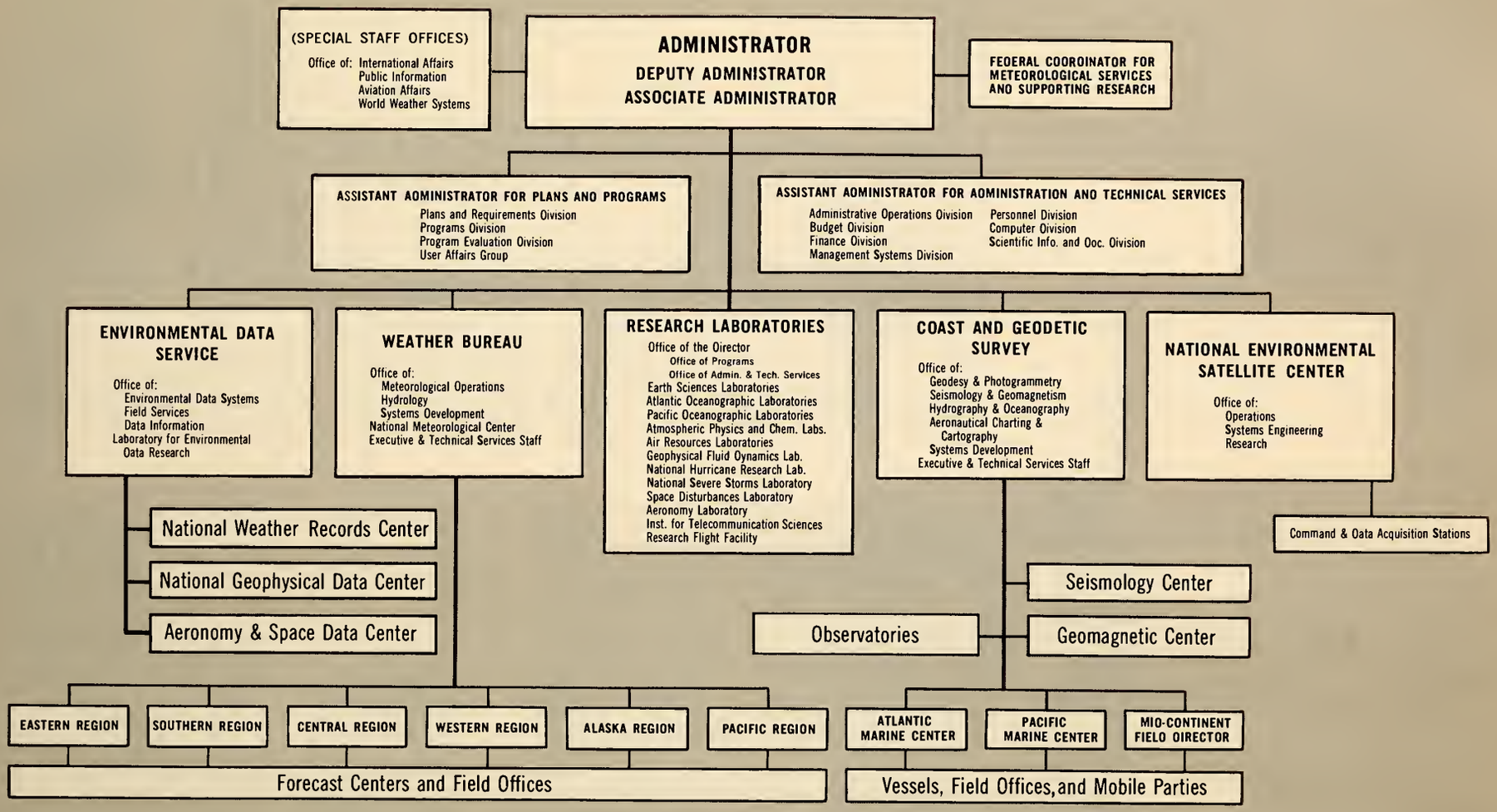
On September 8, 1967, the ESSA Headquarters organizational structure was modified to consolidate the Offices of Planning and Program Evaluation, Science and Engineering, and User Affairs into a single Office of Plans and Programs, headed by an Assistant Administrator. This Office is divided into three Divisions and one Group: Plans and Requirements Division, Programs Division, Program Evaluation Division, and User Affairs Group. This reorganization provides ESSA with a focal point to develop, implement, and maintain a program planning system to achieve ESSA's objectives. The Office has the responsibility to provide a continuing evaluation of ESSA programs and accomplishments, to give advice and guidance to the Administrator, and to initiate action on program aspects of resource allocations, retrenchments, and reprogramming.

Personnel within this Office of Plans and Programs, in cooperation with ESSA line and staff organizations, develop a comprehensive 5-year program and compatible financial plan from which budgets can be formulated for the Administration. The Office is also responsible for a continuing coordination and evaluation of ESSA programs, accomplishments, and user relations.

The Administrator, Deputy Administrator, Associate Administrator, and Directors of each MLC provide many of the requirements and receive most of the resulting products of the Office of Plans and Programs. Personnel from this Office work with members of the Office of the Assistant Administrator for Administration and Technical Services (ADTECH), particularly the Divisions of Budget, Finance, Management Systems, and Scientific Information and Documentation. Similarly, there is direct and continuing interaction with counterpart planning, programming, and systems analysis staffs throughout ESSA, the Department of Commerce (DOC), and interagency groups or activities involving the Federal scientific and technical community.

The second reorganization in ESSA Headquarters occurred within the ADTECH Office structure. On the effective date, January 31, 1969, the Management and Organization Division and the Management Systems and Information Division were merged into a Management Systems Division. This reorganization provides unified staff assistance to develop and improve management systems that ESSA's organizational elements require in program direction and planning.

This new Division, cooperating with the Computer Division of ADTECH, is responsible for the development of advanced administrative management and information systems. Activities essentially involve a centralized automatic data processing (ADP) system which collects, processes, and disseminates information to managers on program



U.S. Department of Commerce, Environmental Science Services Administration organization chart in effect on June 30, 1969.

status and performance. Division personnel plan management systems for measuring production and performance and provide these systems with computer programming support for ESSA staff offices and ADTECH divisions. The Management Systems Division is divided into one Center and two Branches: Management Information Center, Systems Evaluation and Programming Branch, and Management Analysis Branch.

The Environmental Sciences Group (ESG) of the NESC was authorized on January 16, 1966, and activated on September 22, 1967. Recognition by the NESC of the need to investigate the possibilities for applying satellite data to nonmeteorological problems led to the authorization of the Group. The Meteorological Satellite Laboratory (MSL) of NESC found it was conducting investigations into the use of satellite photography and infrared measurements for defining the areal extent of snow fields, for plotting sea ice conditions, and for mapping sea-surface temperatures. While these investigations had some meteorological significance, they were not strictly meteorological problems which are the concern of the MSL. Upon activation, the ESG became responsible for existing investigations on the application of satellite data to hydrology and oceanography. More importantly, the Group started investigations into the possibilities of using satellite-borne sensors to measure parameters applicable to the entire spectrum of earth resources and environmental problems. The ESG maintains close liaison with other Government agencies, university groups, and private research investigations in the planning and implementation of experiments and investigations within its areas of responsibility.

The second reorganization within an MLC during the reporting period became effective on November 9, 1967, with the designation of the Institutes for Environmental Research (IER) as the Research Laboratories (RL)—11 Laboratories, one Institute, and one Facility—all reporting to one Director. (The original establishment of IER in 1965 was a revolutionary organizational approach—the creation of a unified concept of mission support for all ESSA program objectives involving environmental sciences and technology.) The objective of the reorganization was to reflect the scope and mission of the various elements more precisely. These new Laboratories include: Earth Sciences, Atlantic Oceanographic, Pacific Oceanographic, Atmospheric Physics and Chemistry, Air Resources, Geophysical Fluid Dynamics, National Hurricane Research, National Severe Storms, Space Disturbances, Aeronomy, and Wave Propagation. The Institute for Telecommunication Sciences and the Research Flight Facility are the remaining elements of the RL.

The formation of the RL permits each Laboratory Director to have a direct communication channel to the Director, RL, and encourages interdisciplinary cooperation between the various scientific fields. The research activities of this MLC continue to involve investigations of the solid earth, oceans, atmosphere, and near space.

An Office of Programs was established within the Office of the Director, RL. Various staff functions are now within this new Office, including policy management advice to the Director, program planning activities and liaison, coordination of RL activities in national and international scientific programs, and review and evaluation of current programs and plans.

Briefly, the functions of each of the 11 Laboratories in the RL are summarized below.

The *Earth Sciences Laboratories* (ESL) conduct research in geomagnetism, seismology, geodesy, and related earth sciences, seeking fundamental knowledge on the earthquake processes, the earth's internal structure, and an accurate configuration and distribution of the earth's mass.

The *Atlantic Oceanographic Laboratories* (AOL) and the *Pacific Oceanographic Laboratories* (POL) perform oceanographic research to improve understanding of the state and processes of the ocean basins, land-sea interactions, and sea-air interactions required to improve the marine scientific services and operations of ESSA.

The *Atmospheric Physics and Chemistry Laboratory* (APCL) initiates research on those atmospheric processes important to meteorology such as cloud physics and precipitation, chemical composition, and nucleating substances in the lower atmosphere; the Laboratory designs and conducts experiments to find feasible methods for practical weather modification.

The *Air Resources Laboratories* (ARL) conduct research on diffusion, transport, and dissipation of atmospheric contaminants and perform laboratory and field experiments to develop methods for prediction and control of atmospheric pollution.

The *Geophysical Fluid Dynamics Laboratory* (GFDL) investigates the dynamics and physics of geophysical fluid systems, using mathematical modeling and computer simulation to obtain a theoretical basis for understanding and predicting the behavior and properties of the atmosphere and oceans.

The *National Hurricane Research Laboratory* (NHRL) studies hurricanes and other tropical weather phenomena by observational, analytical, and theoretical means, and performs experiments in hurricane modification to gain an understanding of these phenomena and to improve methods for analysis and prediction of the formation, movement, and intensity of tropical storms.

The *National Severe Storms Laboratory* (NSSL) promotes studies to improve the understanding of tornadoes, squall lines, and thunderstorms and to provide capabilities for their prediction, early detection, and identification.

The *Space Disturbances Laboratory* (SDL) conducts research relating to prediction and monitoring of fluctuations and disturbances in the space environment, particularly those associated with solar activity, and provides forecast and warning services from the Aeronomy and Space Data Center. The Laboratory's research efforts apply directly to man's use of the upper atmosphere and space.

The *Aeronomy Laboratory* (AL) studies the physical and chemical processes of the ionosphere and exosphere of the earth and other planets, using theoretical, laboratory, rocket, satellite, and ground-based data.

The *Wave Propagation Laboratory* (WPL) acts as a Federal focal point for research directed toward the extension of telecommunications to higher frequencies and toward the development of new methods for remote sensing of the geophysical environment.

The *Institute for Telecommunication Sciences* (ITS) maintains continuity as the central Federal agency for research and services in support of the U.S. telecommunications industry. The ITS has a dual role—to foster scientific advances in the field of telecommunications and to formulate and implement telecommunication policies within the Federal Government. The Institute represents the Federal Government on the International Radio Consultative Committee, an organ of the International Telecommunications Union.

Lastly, the *Research Flight Facility* (RFF) secures atmospheric and other environmental measurements for the RL or any of the other ESSA components, using aircraft specifically instrumented for research activities.

From 1964 to 1968, a task group within the Systems Development Office (SDO) in the WB Headquarters gathered information to devise a new long-range forecast system reorganization program. The present forecast production system has continued without significant change for a considerable time. But, because of advances made at the National Meteorological Center (NMC) and the National Hurricane Center (NHC) and the success of the National Severe Storms Forecast Center (NSSFC), the present forecast system has become obsolete; a new three-level echelon forecast organization to replace the present organization was proposed by the task group. This new field forecast organization was implemented within the WB on April 5, 1968.

The new forecast organization provides a direct flow of forecast information from the first-level echelon, consisting of the NMC, NHC, and NSSFC, to the second-level echelon of Weather Bureau Forecast Offices (WBFO) which prepare and issue forecasts and warnings. Coordination for warnings which apply to weather phenomenon moving from the area of one WBFO to that of another will be handled by one facility in each Region—the Regional Weather Center (RWC). This new RWC will also monitor the performance of each WBFO in real-time.

All WBFOs operate directly with guidance materials from the NMC. Some WBFOs have minimum programs of public and aviation terminal forecasts; others have programs of a wide variety and great depth, ranging from public forecasting to aviation, agricultural, marine, and possibly air pollution forecasting.

Approximately 50 WBFOs are scheduled to be established within a 5-year period ending in 1973. Under the reorganized forecast structure, the 24 former Area Forecast Centers will become WBFOs. To meet the stated goal, approximately five new WBFOs will be established each year for the next 5 years.

The remainder of the existing WB operating locations, approximately 200, are designated as third-echelon Weather Bureau Offices (WBO). These Offices disseminate to users those forecast products received from the WBFO. Dissemination is made by ESSA Weather Wire, very high frequency (VHF) radio, automatic telephone devices, and mass media. The WBO is responsible for issuing warnings based upon known weather hazards and for preparing local forecasts as adaptations of the WBFO forecasts. In addition, ESSA Climatologists are stationed in nearly every state at either WB facilities, universities, or separate offices to provide advice on uses, applications, and availability of climatic data for planning studies.

In August 1966, a report was submitted to the Director, C&GS, outlining systems development potentialities for that component. To define the direction of a C&GS systems development program, two goals were set. The first goal is to enhance the technical capabilities of C&GS through development, improvement, or application of new systems to satisfy mission requirements. The second goal is to find new ways to employ the technical capabilities of C&GS to serve the needs of ESSA, DOC, and the scientific community. This report proposed an organizational structure to implement a systems development program for the C&GS.

Specifically, the following recommendations were included in the report. First, the C&GS should establish an Office of Systems Development (OSD). Second, the OSD should generate immediate plans based upon the contents of this report, and should initiate prompt action or study of systems programs, as appropriate, using outside talent when necessary. Third, the initial plans for systems development should include the study and evaluation of a comprehensive ADP system and the study of oceanic programs. Fourth, within 6 to 8 months after the OSD is established, studies leading to the C&GS portion of the Federal Oceanic Exploration and Mapping Program should be complete; these studies should focus on a technical development plan, systems development plan, and acceleration of systems development. Fifth, the Office of Seismology and Geomagnetism should prepare and submit a phased technical development plan for the Pacific Tsunami Warning System, including the monitoring and the cost effectiveness of any prospective advanced systems. Sixth, applied research should be accelerated on the subjects of tsunami dispersion, transition, and run-up.

An Office of Systems Development was established in C&GS on April 11, 1968. The structure, organization, capabilities, and function of this Office are parallel to the SDO in the WB. The establishment of such Offices in both components reflects an increasing awareness by MLC management of the importance of the systems approach to day-to-day management, long-range planning, and R&D. The C&GS's Office consists of a Support Services Group and an Engineering Development Laboratory.

The responsibilities of the OSD are to plan, design, and develop systems for the description, mapping, and chart-

ing of the earth and for those hydrographic and oceanographic program elements which involve more than one major C&GS program or need special attention and support. The OSD also is responsible for encouraging systems development efforts by other offices and field units within the C&GS, for recommending the assignment of systems development to be managed by offices and field units, and for developing guidelines to implement systems development. This Office also develops, tests, and evaluates systems and systems components—including instrumentation, equipment, and related manning and operational doctrines—and translates research results into C&GS operational systems.

Major Program Areas

ESSA provides the nation with warnings of natural hazards, such as hurricanes, tornadoes, floods, tsunamis, and air pollution. The Administration collects and provides information essential to weather prediction; to sea, air, and space navigation; to earth and ocean mapping; and to understanding environmental phenomena such as geomagnetism, seismology, and climatic and atmospheric effects upon telecommunications. These varied environmental aspects are organized in six major funding categories—Weather Forecasts and Warnings; River and Flood Forecasts and Warnings; Earth Description, Mapping, and Charting; Marine Description, Mapping, and Charting; Telecommunications and Space Services; and Environmental Satellite Services.

These funding categories include eight service activities—Weather Forecasts and Warning Services; River and Flood Forecast and Warning Service; Earth Description, Mapping, and Charting Service; Marine Description, Mapping, and Charting Service; Telecommunications and Space Service; Environmental Satellite Service; Environmental Data

ESSA service responsibilities which benefit from research and development support.

Service; and Research. Each of ESSA's five MLC's are assigned specific responsibilities for portions of these eight service activities as part of the DOC's Program Category—the Physical Environment.

The eight service activities are described briefly below, but are discussed in greater detail in the next chapter.

Weather Forecasts and Warning Services

These Services describe current meteorological conditions, prepare and disseminate related forecasts and warnings, and provide statistical evaluations and engineering applications of historical climatological data.

River and Flood Forecast and Warning Service

This Service supplies the Nation with flood forecasts and warnings, water supply forecasts, and continuous forecasts of river stage, flow, and velocity. The Service also involves hydrometeorological studies and analyses useful for the allocation of water resources through planning, design, and management.

Earth Description, Mapping, and Charting Service

This Service concerns itself with precise measurement of the physical parameters of the earth; distribution in strength and direction of the earth's magnetic field; location and intensity of earthquakes and tsunamis; initiation of seismological studies of the earth; and publication of charts for air navigation.

Marine Description, Mapping, and Charting Service

This Service provides for charting the coastal waters of the United States and its possessions to promote safe navigation; for systematic mapping of the U.S. Continental Shelf and selected deep ocean areas to determine bathymetric, geophysical, and geological properties of the ocean floor and subbottom structure; and for describing the physical, chemical, and dynamic properties of the water mass. Products of this Service include nautical charts, bathymetric maps, geological and geophysical maps, physical and chemical data compilations and atlases, tide tables, tidal current charts and tables, sea level information, and estuarine flushing rate predictions.

Telecommunications and Space Service

This Service describes and predicts the properties, conditions, and disturbances of the upper atmosphere and space which can influence the use of these areas as a telecommunications medium, can affect man and materials in the exploitation of those areas, or can affect other regions of the environment. The Service also initiates research to facilitate full exploitation of the electromagnetic spectrum for telecommunications.

Environmental Satellite Service

This Service establishes and operates the National Environmental Satellite System and exploits and coordinates ESSA's use of space platforms for environmental observations. This Service supports the Nation's environmental services by collecting, processing, and disseminating to user agencies data obtained from orbiting spacecraft systems—polar-orbiting and synchronous—on the states of the atmosphere, the oceans, and the earth.

Environmental Data Service

This Service collects, processes, quality controls, archives, publishes, disseminates, and retrieves worldwide environmental data gathered by ESSA from their own components, other agencies, and foreign countries for such purposes as weather forecasting, mapping, and climatic description. This Service involves data in such fields as climatology, aeronomy and space, solid earth, and marine systems, and assists industry, the scientific and engineering community, and the general public in the application of historic data and statistics to engineering, planning, and design problems.

Research

ESSA's research programs are directed toward improved knowledge and more complete understanding of the physical environment. Special emphasis is placed upon the needs of the descriptive and predictive services for the use, control, and modification of this environment.

3 GOALS

Department of Commerce Order 2A directs ESSA to make a broad study of the physical environment. Essentially, this study relates to two specific responsibilities of the Administration: description and understanding of the environment and prediction and warning of environmental hazards.

ESSA's Goals

During the reporting period, ESSA's Office of Plans and Programs developed four goal areas that are consistent with the Department Order. These goal areas which serve as a framework for planning purposes include:

- Protecting life and property from environmental hazards;
- Promoting economic development;
- Contributing to the maintenance of physical environmental quality; and
- Contributing to the use and enjoyment of the physical environment by individuals as consumers.

Because of the continuing and developmental nature of these goal areas, both short- and long-range aspects must be considered. All four goal areas relate to service activities conducted by ESSA's five Major Line Components (MLC) and to ESSA's research and development (R&D) program.

The relationship between a goal area and a specific service activity or an R&D program element cannot always be formulated on a "one-to-one" basis. Because of the diversity and multidisciplinary nature of ESSA's missions, such one-to-one relationships would not be desirable. The R&D effort within ESSA can support more than one goal area and be within more than one MLC; therefore, such effort must be reviewed within its own separate context. Moreover, certain R&D program elements or service activities—for instance, the products of the Basic Weather Services—may be applicable to all four goal areas.

Protecting Life and Property from Environmental Hazards

A subprogram of all of the MLCs within ESSA is the Nationwide Natural Disaster Warning (NADWARN) System. This System, when fully operational, will afford a means for detecting various environmental hazards, communicating the dangers to the public, educating the public on safety precautions, and preparing communities for effective action. Included in the System will be capabilities for extended river forecasts; airspace environmental disturbance warnings—both clear air turbulence (CAT) and solar; hurricanes, tornadoes, floods, and severe local storms forecasts; and, earthquake and tsunami warnings. Budgetary limitations have permitted the MLCs to initiate only portions of the entire NADWARN System; units have been placed in operation mainly at a large number of Weather Bureau Forecast Offices (WBFO).

The goal of ESSA in this area is to protect human life and reduce property losses from environmentally caused disasters. Efforts in this goal area are concentrated on achieving consistency with the objectives of the NADWARN System. Examples of some program elements supporting this goal area follow.

The Weather Bureau's (WB) Meteorological Services reduce death and injury from such atmospheric disturbances as tornadoes, severe local storms, hurricanes, and other oceanic-derived storms by providing specialized forecasts, warnings, and advisories to the general public and specialized user groups, public and private; these activities are pursued through the hurricane and tornado program element which includes the operation of specialized forecast and warning centers, specialized communication and processing activities, and requisite supporting R&D. The WB furnishes the public with such output products as advisories, bulletins, and statements; coordinated prognostic hurricane positions; tropical weather analyses and outlooks; post storm reports; severe weather watches, warnings, bulletins, and statements; and outlooks and synopses of severe weather conditions.

The Environmental Data Service (EDS) uses its climatological data holdings to assist people working in such diverse areas as building and airport design, aviation engineering, agricultural planning, disease and insect control, and severe storm analysis. Historical records are used to inform the public about expected weather conditions in the country.

The National Environmental Satellite Center (NESC) makes a major contribution to protection of life and property from hurricanes, typhoons, and other oceanic storms through daily television photographs of worldwide cloud cover. Satellite storm advisories are sent directly to the meteorological services of all countries which may lie in the path of such storms; these advisories have been credited with substantial saving of life and prevention of injury since their introduction several years ago.

The WB's Hydrological Services work toward the reduction of death and injury from floods and coastal inundations through a river and flood forecasting and warnings program. Products provided by these Services include generalized flood warnings, specific flood forecasts, routine river-stage forecasts, water-supply forecasts, seasonal water-supply forecasts, flood potential information, and flash-flood warnings. The program element requires that needed hydrologic data —such as precipitation and river stages—be collected, processed, and disseminated to users in prepared forecasts or warnings over network circuits.

The Coast and Geodetic Survey (C&GS) strives to reduce death and injuries from seismic disturbances such as earthquakes and tsunamis; such activities are included in the general program element of seismology. This element consists of those activities which provide the seismological data and information required to locate earthquakes more precisely; to assist in developing design criteria for earthquake-resistant structures; to issue advance warnings of tsunami arrival times; to initiate R&D studies on the core, mantle, and crust of the earth, leading ultimately to the development of a means to predict earthquakes; and, to develop instrumentation for seismic, tidal, and tsunami warning systems. Major products of this program element involve seismological bulletins and reports, engineering data and information, tsunami warnings, and instrumental systems.

Promoting Economic Development

Several of ESSA's goals for promoting economic development are oriented toward assisting individuals, private business organizations, and Government agencies to use the physical environment resources in producing economic goods and services more effectively, and to aid the various sectors of the national economy in maximizing economic gain and minimizing loss sustained from environmental causes. Support for these goal areas are given below for certain of the program elements.

The Aviation Weather Service of the WB proceeds to promote the safety of air navigation and the economic use of the Nation's air space through the aviation weather program element by furnishing specialized observations, forecasts, warnings, and advisories at the international, national, regional, and local levels. Quality control of forecast products, pilot briefings, and meteorological support for aviation safety investigations are provided for a geographical area by the Regional and Central Headquarters Offices of the WB. Products of the aviation weather program element are air terminal observations; forecasts or warnings for guiding terminal operations; and en route CAT, severe weather, winds and temperatures aloft, and other significant weather parameters. Automatic Picture Transmission (APT) products are used by the Aviation Weather Service for briefing air crews.

The C&GS's Office of Aeronautical Charting and Cartography furnishes aeronautical navigation charts and varied information required for the safe and efficient navigation of commercial, private, and military aircraft. Major products of this aeronautical charting program element are various types of aeronautical charts and Airport Obstruction Charts. Special studies are conducted in chart display techniques and automated chart production.

The Marine Weather Service (MWS) of the WB promotes the maximum use of safety to commercial marine navigation interests in the inland and territorial waters of the United States and on the high seas through its program on marine weather. The MWS provides specialized observations, forecasts, warnings, and advisories designed to contribute to the safety and efficiency of marine operations. Particular emphases in the program element are placed on wind and sea conditions affecting small boats and on major storms affecting commercial shipping. Products of this program element are warnings of expected hazardous conditions, routine forecasts, and coded analysis; these products are issued by selected WBOs.

The C&GS's Office of Hydrography and Oceanography provides through the marine navigational charting program hydrographic information for the coastal waters and intracoastal waterways of the United States and its possessions to vessels engaged in commercial, industrial, recreational, and national defense activities. Major products are nautical charts, *United States Coast Pilots*, and related navigation information. Special studies concentrate on automated chart production; hydrographic systems; the introduction of new or improved hydrographic data acquisition systems, data loggings, and storage and retrieval systems; data processing systems, including cartographic compilation and presentation; and data dissemination.

The EDS participates in the collection of marine data, evaluates the frequency of severe storm damage in coastal areas, assists shipping companies with data on the frequencies of heavy winds and high seas for all oceans, and conducts ship load design studies.

The WB's Agricultural Forecast Offices (AFO), supplemented by the Agricultural Service Offices (ASO), work to enhance the economic production and use of agricultural and forest products and to protect against losses resulting from environmental factors. Both Offices provide an agriculture weather program of specialized observations, forecasts, warnings, and advisories for the agricultural community. The AFOs are concerned with parameters of known

significance to agricultural operations—soil temperatures and moisture for planting; temperature, humidity, wind, and dew for drying, spraying, and dusting operations. The ASOs, located at Agricultural Experiment Stations, furnish guidance on the relationships between weather and crops, life cycles of pests, cultivation techniques, and other agricultural operations. Fruit and vegetable growers in 5 states receive specialized frost warnings. The EDS has an office within the Department of Agriculture (DOA) to provide advice and guidance on agricultural climatology programs.

The Telecommunications and Space Services of the Research Laboratories' (RL) Institute for Telecommunication Sciences (ITS) provide research and consultation services, and develop, describe, and predict the environmental factors affecting the radio propagation program to promote the economic use of the electromagnetic spectrum. The Telecommunications and Space Services report actual and predicted conditions in the ionosphere—the region of the upper atmosphere which provides a telecommunications medium by reflected radio waves—and make possible continued research and prediction necessary for successful long-range ionospheric telecommunications.

Contributing to the Maintenance of Physical Environmental Quality

Another of ESSA's stated goals is to assist, create, and maintain satisfactory physical environmental quality by providing measurements and other technical bases for the development of harmonious relationships between man and his physical environment.

In progressing toward this goal, ESSA research involves such environmental interfaces as the solid earth and its fields, earth and ocean, earth and atmosphere, ocean and atmosphere, ionosphere and atmosphere, ionosphere and space, ionosphere and the earth's field, and space and the earth's field. Additionally, ESSA is concerned with developing ways to measure and predict the impact of alternative economic development patterns or other social choices on environmental quality.

A basic role of ESSA in this goal area is to measure and predict the state of the atmosphere, and the stage and flow of the rivers, streams, estuaries, and other bodies of water as these parameters affect environmental pollution in the United States. An important program effort is directed toward air pollution.

The air pollution program of the WB provides specialized observation forecasts and advisories to Federal, State, and local air pollution agencies on the atmospheric dilution, transport, and deposition of pollutants. Research is conducted within the general area of atmospheric dynamics—particularly mesoscale studies on meteorological diffusion, transport, and deposition of atmospheric contaminants—to increase the understanding of the atmospheric pollution processes leading to prediction and abatement procedures.

Contributing to the Use and Enjoyment of the Physical Environment by Individuals as Consumers

The final goal of ESSA is to assist consumers in the safe, effective use of the resources of the physical environment. This involves such major ESSA program elements as public weather forecasting, aviation weather, marine weather, and radio propagation. Programs concerned with consumer benefits are not separate entities in themselves, but are related to portions of the overall ESSA program structure described earlier in this chapter.

One program element not discussed previously involving benefits to the consumer is public weather forecasting. The Public Weather Service (PWS) of the WB provides information which includes the prediction, dissemination, interpretation, presentation, and display of current or expected weather conditions to the general public and other Government agencies. This information is transmitted from centralized analysis, prognosis, and forecast groups—National Meteorological Center (NMC), National Hurricane Center (NHC), and National Severe Storms Forecast Center (NSSFC)—to WBFOs and local Weather Bureau Offices (WBO). The output from the PWS consists of local information bulletins and charts, detailed operational guidance materials, briefings, and communications of current weather forecasts and warnings to the general public.

Research and Development Goals

ESSA conducts considerable R&D in support of the missions of all five of its MLCs. The C&GS and WB are primarily service-oriented, yet provide much of their own internal scientific and technical support through systems development projects. The NESC acquires, processes, and disseminates satellite data to users, and conducts research into extracting the maximum amount of information from satellite data and designing new instrumentation for measuring environmental data from a space platform. The EDS has responsibility for both service activities and R&D programs in data storage, retrieval, and dissemination of environmental data. Lastly, the RL are accountable for exploratory and low-range R&D, but also have responsibilities for service activities involving space disturbances forecasting and ionospheric and tropospheric telecommunication predictions.

Earth Sciences

Research is underway in RL to support programs in earth sciences, oceanography, meteorology, and telecommunications and space. The research programs in earth sciences—geodesy, geomagnetism, and seismology—are on projects to develop improved means for measuring the size and shape of the earth, and to increase knowledge on the structure and behavior of the earth's interior, the gravitational and magnetic fields of the earth, and the interaction of these fields with other elements of the physical environment.

Long-range programs in geodesy concentrate on the development of precise methods to determine the locations

of points and boundaries on the earth's surface. Basic research involves modeling the distribution of mass within the earth through studies of the gravitational field. Geodesy programs support the national space effort by providing information on gravity field anomalies that cause irregularities in satellite orbits. Research in geodesy also supports new capabilities for worldwide geodetic datum correlations.

Research scientists in geomagnetism investigate the quasi-permanent magnetic field associated with the earth's interior, including the field's origin, secular change, and possible long-term reversal. The quasi-permanent field is studied in relation to the solar-induced magnetic field; the combined effects upon telecommunications and radiation levels in near space are thus determined. Research is also applied to problems in navigation, mapping and charting, and telecommunications.

Long-term R&D objectives in seismology are to provide accurate methods for predicting moderate to severe earthquakes and ultimately to achieve engineering techniques for dissipating seismic energy harmlessly. Specifically, the structure of the earth's interior is investigated through seismological data. Understanding this structure and the motions of the solid earth resulting from gravitational compaction and thermal convection are fundamental to comprehending the distribution of land and sea, drift of continents, morphology of ocean basins, and global distribution of earthquakes. Basic research is conducted on the mechanics of earthquakes, crustal movements of the earth, epicenters of strong-motion earthquakes, relation of microearthquakes to moderate or severe earthquakes, and causes and effects of tsunamis.

Oceanography

The oceanography programs are intended to gain knowledge of the physical properties and behavior of the oceans and their interactions with land and air, and to acquire a fuller description and understanding of the boundaries between the oceans and solid earth. Specific investigations include structure and motion of oceans, land-sea interaction, ocean basin characteristics, and sea-air interaction.

Research on the structure and motion of oceans—the physical and dynamic properties—stresses the description of ocean circulation both by descriptive inference and by application of dynamic theories and models. Additionally, the weather phenomena of tides, winds, and internal ocean waves are investigated; studies are also made of mesoscale hydrodynamics in estuarine, nearshore, and ocean environments to understand ocean turbulence, estuarine circulation and flushing, energy transform mechanisms, and boundary currents.

Studies in land-sea interaction focus upon the response of shore, estuarine, and Continental Shelf sediments to environmental and manmade changes. These changes are pursued through the investigation of atmospheric and oceanic forces that act upon boundaries of transition zones in the atmosphere-land-ocean system.

Investigations into ocean basin characteristics relate to the ocean floors, continental margins, and crust and mantle in ocean basins, all leading to a greater understanding of marine morphology, marine geophysics, deep sea floor, and ocean sedimentology. The methods employed provide interpretive descriptions of the hypotheses and the genesis of ocean basins, margins, and features.

Projects in sea-air interaction develop techniques for data acquisition and advance and test theoretical hypotheses involving the exchange processes of mass, momentum, and heat between the atmosphere and oceans. Research also includes techniques for shipboard logging of data while underway, systems for sampling planetary boundary layers and making micrometeorological observations over water, and sensor development for measuring sea-air parameters during high winds at sea.

Studies have been initiated within the NESC involving intensive investigations of the ocean surface, interactions between the sea and the atmosphere, and temperature structure of the ocean by means of satellite sensors. The sea-surface state is being estimated by analyzing the reflection of the sun seen in satellite pictures; such analyses will yield estimates of surface wind speeds in remote areas. Temperature fields and ocean currents are being mapped; the information will aid meteorological and oceanographic investigations.

Meteorology

The meteorology programs involving R&D are aimed at investigating the feasibility of climate and weather modification, and increasing the knowledge of the physical properties of behavior of the lower atmosphere and the interaction of this lower atmosphere with surface waters, land, upper atmosphere, and the sun. Investigations are pursued in atmospheric dynamics, weather modification, hurricane research, and severe local storms research.

The R&D efforts in atmospheric dynamics are directed toward the understanding and prediction of large-scale atmospheric and oceanic circulation systems and toward the interactions that relate to processes for and exchanges of momentum, water vapor, and latent energy. Numerical methods are under development to extend forecasts of the physical state of oceans and atmosphere. Related mesoscale research in meteorological diffusion, including transport and deposition of atmospheric contaminants, is performed to increase the understanding of atmospheric pollution processes that lead to prediction and abatement procedures. Atmospheric turbulence-and-diffusion research is conducted for the Atomic Energy Commission (AEC) at its request.

Basic and applied research are underway in weather modification and in the physics and chemistry of those processes affecting the atmosphere, particularly the lower atmosphere. The research aim is to increase the understanding of such atmospheric physical properties as physics of clouds and precipitation processes, and of such atmospheric chemical compositions as ozone, carbon dioxide, and cloud- and precipitation-nucleating substances.

Activities in hurricane research involve investigations of

hurricane and other tropical weather phenomena through observational, analytical, and theoretical studies. Theoretical and numerical methods are used to analyze tropical weather systems. Through use of surface and airborne weather data, the structure and circulation of hurricanes and other tropical systems are being investigated. Photographs from Environmental Survey Satellite (ESSA) spacecraft and time-lapse films of pictures from the National Aeronautics and Space Administration's (NASA) Applications Technology Satellite (ATS) spacecraft are provided additional material for studies on the broader scale aspects of tropical weather systems. Research is also underway on improvements in techniques for forecasting genesis, motion, and intensity of hurricanes. Abatement experiments on hurricanes and other tropical storms are conducted to find the means for beneficial control, to provide safety at sea, and to improve understanding of sea-air energy exchange mechanisms.

Research on severe local storms focuses on the study—particularly the techniques for detection—of tornadoes, squall lines, and thunderstorms. Data for this research are obtained from a high density network of weather stations and instrumental towers, serial releases of rawinsondes, conventional and experimental weather radars, electric field monitors, and instrumented aircraft. Advanced techniques are developed to probe the atmosphere and experimental radar and passive microwave radiometers.

Telecommunications and Space

Within the program element of telecommunications and space research, investigations are underway on the structure and behavior of the upper atmosphere and on the interaction of this upper atmosphere with the physical environment, solar radiation, and cosmic radiation. Specifically, investigations are underway on the electromagnetic spectrum utilization, environmental factors of communication technology, space environment research, and upper atmospheric research.

Research in electromagnetic spectrum utilization stresses means to use the telecommunication channels in the electromagnetic spectrum more completely and to improve the effectiveness of broadcast, modulation, and reception systems. Because the spectrum is rapidly approaching saturation, several research approaches are under investigation to relieve this congestion, including multiple-access time-sharing and intensified frequency-sharing systems. In addition, extensive research is conducted on spectrum extension —opening a higher frequency portion of the spectrum for telecommunications through development of optical, infrared, submillimeter, and millimeter wave propagation techniques.

Scientists are conducting research into environmental factors of communication technology to find those natural environment properties which affect the performance of telecommunications. Specifically, studies involve the electrical and geophysical properties associated with variations of the earth's surface; the refractive index in the troposphere and ionosphere resulting from solar variations, geomagnetic disturbances, and meteorological disturbances; and the prediction and warning methods for selecting transmission frequencies.

Efforts in space environment research concentrate on the analysis of the physics of fluctuations and disturbances in the space environment having important application to upper atmospheric utilization and leading to improved monitoring and prediction. Emphases are on solar emissions producing significant particle and radiation impacts upon the earth, on the interaction of these impacts with the atmosphere, and on several programs involving the atmosphere —such as man in space and supersonic transport (SST).

The upper atmospheric research activities involve study of the physical and chemical processes controlling these portions of the atmosphere, including the ionosphere, upward from approximately 50 kilometers. Research efforts are directed toward establishing an ability to predict those upper atmospheric conditions which can be used in space activities and telecommunications. Emphases are placed both on laboratory studies of the basic processes and on global surveys, particularly the variable conditions of the ionized and neutral components of the upper atmosphere.

The R&D programs of NESC are concentrated in data usage and development of satellite sensors. The satellite systems for which data are obtained and sensors are designed are a polar-orbiting satellite system and a geosynchronous "stationary" satellite system—a mix of operational and R&D satellites.

The current polar-orbiting ESSA spacecraft, comprising the TIROS (Television Infrared Observation Satellite) Operational Satellite (TOS) system, obtains daily global observations of the earth and its atmosphere from approximately 900 statute miles above the earth. NASA's Nimbus R&D satellite program conducts flight tests of the R&D test vehicle for instruments under consideration for use in future operational system satellites. A second-generation operational system, the Improved TOS (ITOS), will use a spacecraft with a daytime camera capability and a day-night infrared sensor capability. The first ITOS spacecraft, due for launch in January 1970, will carry a solar proton monitor in support of ESSA's Space Disturbances Laboratory (SDL).

Geosynchronous satellites in orbit at 22,300 statute miles appear to hover above a point on the earth's Equator. From this altitude, the spacecraft sensors can view a disk of the earth that is approximately 60 degrees of latitude in radius. The frequency of viewing, which varies from 15 to 30 minutes per picture, permits the making of time-lapse film which is used to study cloud and storm morphology and for the extraction of wind information. These satellites can also be used to collect data from *in situ* observing stations and to relay the data to central collection points or to individual users. NASA's ATS 1 and 3 have served as the predecessors to the R&D prototype of the planned Geostationary Operational Environmental Satellite (GOES) system now under intensive development.

Part of the research needed for the design of new or improved satellite sensors involves studies of the transmissive and radiative properties of the atmosphere. Data acquired

by sensors on earlier TIROS R&D spacecraft are useful in these studies. Some of the instruments under design or in fabrication include the Satellite Infrared Spectrometer (SIRS), Infrared Temperature Profile Radiometer (ITPR), High Resolution Infrared Radiometer (HRIR), and Vertical Temperature Profile Radiometer (VTPR).

Environmental Data Service

The goal of the environmental data service program of EDS is to develop more effective ways of processing the increasing amounts of raw data in less time for greater user retrievability. R&D programs in environmental data service focus on developing advanced automated information storage and retrieval methods and new techniques of data representation. Special studies are conducted to develop techniques for the application of nonreal-time data.

Decades after initial collection, environmental data still have relevance. Indefinite retention of data is required; and, as long as the data remain accessible, they have full value over an extended period of time. This accessibility is enhanced through continued R&D projects in archiving, methodology, and devices.

Extensive R&D is undertaken in climatology. Inputs of climatological data, collected over extended periods of time, are especially important in the formulation of mathematical models of the atmosphere. Research in this field covers climatic change, synoptic climatology, severe storm climatology, bioclimatology, urban climatology, and three-dimensional global climatology. Evaluation of climatic modification, necessarily based on historical data, is undertaken by EDS, particularly in the context of the influence such modification has upon crop production.

The supporting R&D relevant to ESSA's major goal areas is discussed in detail in the ensuing chapters. These chapters represent an overview of ESSA, centering on the development and application of knowledge to the key problems in environmental science and technology.

4 WEATHER FORECASTS AND WARNINGS

In terms of funds and personnel, Weather Forecasts and Warnings Service is the largest single service activity of ESSA. Approximately one-half of all full-time ESSA employees are engaged in meteorological and hydrological operations.

During the reporting period, R&D projects in this service activity were conducted in the following program areas: Basic Weather Services; Public Weather Forecasts; Hurricane and Tornado Warnings; Agricultural Weather Services; Air Pollution Service; Weather Modification; Fire Weather Service; Aviation Weather Services; Marine Weather Services; and River Flood Prediction and Warning.

The continued improvement of weather forecasting and prediction, a basic objective of ESSA, depends upon an extensive program of research and development (R&D). To achieve this objective, the Weather Bureau (WB) and the Research Laboratories (RL) of ESSA conduct programs in both basic and applied research; these components of ESSA also exploit new technology developed outside of the Administration for requiring, communicating, processing, and displaying meteorological and hydrological information. New techniques are continually being incorporated into the Weather Forecasts and Warnings Service system.

The primary R&D efforts within the WB are conducted by the Systems Development Office (SDO), the Office of Hydrology, and the National Meteorological Center (NMC). Within the RL, R&D efforts are performed by the Atmospheric Physics and Chemistry Laboratory (APCL), Air Resources Laboratories (ARL), Geophysical Fluid Dynamics Laboratory (GFDL), National Hurricane Research Laboratory(NHRL), National Severe Storms Laboratory (NSSL), and the Research Flight Facility (RFF).

The National Environmental Satellite Center (NESC), a Major Line Component (MLC) of ESSA, also conducts R&D programs that involve weather forecasts and warnings. However, these are discussed in Chapter 8 which treats ESSA's Environmental Satellite Services as a separate entity.

The SDO, located at Silver Spring, Md., appraises the total weather prediction and warning system for ESSA's WB. Activities of SDO encompass the design and improvement of the Public Weather Service (PWS) teletypewriter network; data acquisition subsystem; hurricane and tornado warnings; forecasting of weather services to marine, aviation, agriculture, and other interests; overall weather communication; and cost benefit analyses of weather services in relation to user requirements.

The NMC, located at Suitland, Md., is concerned with both long- and short-range weather prediction problems; its R&D activities are incorporated into routine operations. The NMC supplies the basic forecasting guidance to specialized field forecasting services such as aviation, air pollution, agriculture, marine, hurricane and tornado, and military weather. This guidance is subsequently modified by these specialized services to meet their own needs and to incorporate regional and local efforts.

Several laboratories of the RL conduct basic research in atmospheric sciences. These research results of RL are utilized by the WB to provide more accurate and timely warnings of potential weather hazards. Special research is also carried out by RL in air pollution abatement, weather modification, nature of hurricanes and tornadoes, and mathematical and numerical simulations of the physical behavior and dynamics of the ocean-atmosphere fluid systems to extend and improve the Weather Forecasts and Warnings Service of ESSA.

BASIC WEATHER SERVICES

Service Programs

Weather observations and measurements of the existing state of the atmosphere are the foundation for the public and specialized forecast services and for basic observation services. A Basic Observation Network serves as the primary source for collection of such data in this country.

The Network provides three types of observations—surface, upper air, and radar—with many stations performing

more than one type. Observations are taken at prescribed times, assembled, and entered onto maps or charts which are then analyzed to depict the general weather patterns over large areas. These maps or charts are basic tools used in all weather forecasting and information activities. Selected types of observations are taken hourly (more often when conditions are changing rapidly) to provide data to concerned specialized users, such as for those involved in the operation of aircraft.

Surface weather observations include measurements of air temperature, wind speed and direction, dew point, barometric pressure, sky conditions, cloud height, visibility, and precipitation. Observations are taken at ESSA's WB-operated land stations, automatic meteorological observing stations, cooperative and fee stations, Federal Aviation Administration (FAA) weather reporting stations, Supplementary Aviation Weather Reporting Stations (SAWRS), and cooperating merchant vessels of many nationalities. Approximately 13,000 cooperative stations provide data for measuring climatic variations. These stations provide backup services for the River and Flood Forecast and Warning Network and dispense local public information.

The upper air weather observations involve measurements of pressure, temperature, water vapor, and wind direction and speed at various levels in the atmosphere from the surface to about 100,000 feet. There are two types of upper air observations—rawinsonde and pilot balloon.

The primary type is the rawinsonde. This observation is obtained by sending aloft a balloon-borne instrument, a radiosonde, which measures and transmits to the ground station data on temperature, relative humidity, and pressure as the radiosonde ascends into the atmosphere. Additionally, winds aloft data (direction and speed) are obtained by tracking the radiosonde with a radiotheodolite—ground-based, radio direction-finding equipment—or radar.

The second type of observation, the pilot balloon (pibal), measures wind direction and speed at low levels by visually tracking a free-rising balloon with an optical instrument, a theodolite.

Rawinsonde observations are taken at ESSA's WB-operated land stations, other cooperative stations, and special project stations. Additional observations are also taken by weather personnel on Coast Guard fixed ocean station vessels, at Department of Defense (DOD) stations, and on moving ships—including merchant, military, and ESSA's Coast and Geodetic Survey (C&GS) vessels.

Radar weather observations include the detection and measurement of precipitation and the identification and tracking of severe thunderstorms, squall lines, and other weather systems. Similarly, observations of approaching hurricanes which threaten U.S. coastal areas are fed into the national radar network. Radar observations provide systematic measurements of location, height, and intensity of precipitation; these observations are made hourly when precipitation is observed within the area, and more frequently when conditions indicate severe storms or rapidly changing weather. Local use of radar provides information for short-period forecasts and warnings in the immediate area.

Radar observations are taken at ESSA's WB-operated land stations which are part of a radar network; this network is supplemented by observations from Air Force and Navy installations which participate in a joint Federal interagency network designed to provide 24-hour weather surveillance over critical areas of the Nation. Additional composited observations are produced by WB staffs assigned to the Western Air Route Traffic Control Centers of the FAA.

In an increasing number of locations, low-cost remoting equipment provides weather radar displays in nearby offices, greatly improving the dissemination of observations to other users.

Basic Communications Network

ESSA's WB, FAA, and DOD maintain a high-volume communications system to collect and distribute data from worldwide sources to appropriate processing centers and to disseminate analyses, forecasts, warnings, and bulletins to millions of users. Because both the private and public sectors of our economy are affected by environmental conditions, users find an increasing economic value in weather products and make continuing demands for rapid dissemination of weather information. Reducing the time delay between observations or central analysis and dissemination of weather information provides users with a maximum of useful information and with time for self-protection. Use of special circuits, high-speed equipment, detailed procedures, and automation contributes to this communications objective.

Although most weather communications are domestic, links with networks of adjoining countries and continents are necessary. These international communications networks were established in accordance with the standards promulgated by the World Meteorological Organization (WMO), an affiliate of the United Nations (UN), to facilitate the exchange of weather information.

With the exception of radio and local service equipment, ESSA leases most of its communications equipment. Teletypewriter equipment which delivers hard copy to the user is available in greater quantity than other types of equipment in service, but facsimile is used extensively both nationally and internationally to disseminate satellite photographs, prepared analyses, and prognostics in graphical form. High-speed data links with a capacity of over 3,000 words or more per minute are used in the international exchange and by the computer.

Dissemination of environmental information to the public involves use of the teletypewriter, telephone, telephone-answering recorders, recorded radio broadcasts, electric handwriting devices, and the wide-ranging facilities of radio, television, and newspaper.

For more detailed description of the communications systems available to disseminate weather data, see the annual *Operations of the Weather Bureau* reports.

Research and Development Programs

The primary objective of R&D programs in Basic Weather Services is to provide the basis for future improvements in basic observing systems. Broad systems design and planning studies have been undertaken by the Systems Development Office (SDO) of the WB to examine long-range problems and to provide an overview of the total observing system. These studies assess the technical and economic implications of a variety of basic options that ESSA might select, and often involve fundamental policy issues. In connection with these studies, the SDO is preparing a basic framework to guide these systems through engineering design, development, test, and evaluation of specific observing techniques and equipment for the improvement of current operations. The bulk of the design and development is aimed at providing substantial improvements 5 to 10 years into the future, although a significant portion of the program addresses itself to current operational problems and focuses on short-range solutions.

During FY 69, an analysis of the entire observational system was completed for use in establishing a framework of reference for specific and definitive R&D efforts. As an outgrowth of this analysis, an in-depth study of the long-range role of automation was initiated. As the result of this study, the proper level of automation and the optimal design configuration of an observational system will be specified.

As new systems, techniques, and equipment become available, the operation of the basic observing systems will improve. Specifically, the public will receive the benefits derived from more efficient observations taken of broader portions of the atmosphere which will produce better forecasts and warnings, or both.

Test Facilities

To support the applied R&D activities of the WB, a testing facility, the Test and Evaluation Laboratory (T&EL), is operated and maintained at Sterling, Va. This facility has the necessary land and equipment to provide representative observing sites for simulating a wide range of environment and operating conditions to test meteorological instrumentation, for examining new systems and procedures functionally, and for conducting engineering tests to verify the performance of newly developed equipment and systems.

Communications Equipment and Display

The growth of international cooperation in the field of meteorology has increased the urgency for high-speed, integrated global communications networks. Each delay in collection or dissemination, both of which rely on basic communications systems, reduces the value of basic weather data and of the end product—forecasts and warnings. The development of a telecommunications system to collect and distribute observational weather data worldwide is an important part of ESSA's research activities in communications systems.

Techniques and equipment to increase the speed of data transmission and to improve data display techniques are under study by the WB. Testing and evaluating the usefulness, reliability, and maintainability of communications display equipment are significant parts of the effort.

Forecast Development

ESSA's effort in forecast development is in direct support of the operations of the National Meteorological Center (NMC) and consists of two main activities—numerical weather prediction and extended-range weather prediction. The aim of numerical weather prediction R&D is improved weather forecasts; this is accomplished by placing the analysis and predictions system on a stronger scientific basis through the use of improved theory of atmospheric motions and by applying the most recent developments in numerical techniques. The objective of extended-range prediction R&D is development of improved forecast methods for periods beyond 5 days through systematic application of physical and statistical techniques.

A six-layer primitive equation (PE) prediction model has been in operational use since FY 66 at NMC. A numerical analysis and prediction system for the tropics was operationally tested; a numerical model which predicts daily weather sequences up to 7 days has also been developed and tested. Using a thermodynamic model, experimental monthly forecasts were made to improve predictions of drought, storms, and extreme weather for 2 weeks to a season in advance. Current R&D on numerical prediction is directed toward enhanced physical realism of models, extension to weekly time periods, and expansion to the entire globe. Techniques have also been developed by the NMC during the reporting period for an integrated operational analysis and forecasting program as part of NMC's support to the World Meteorological Center (WMC)—Washington.

Objective Weather Analysis

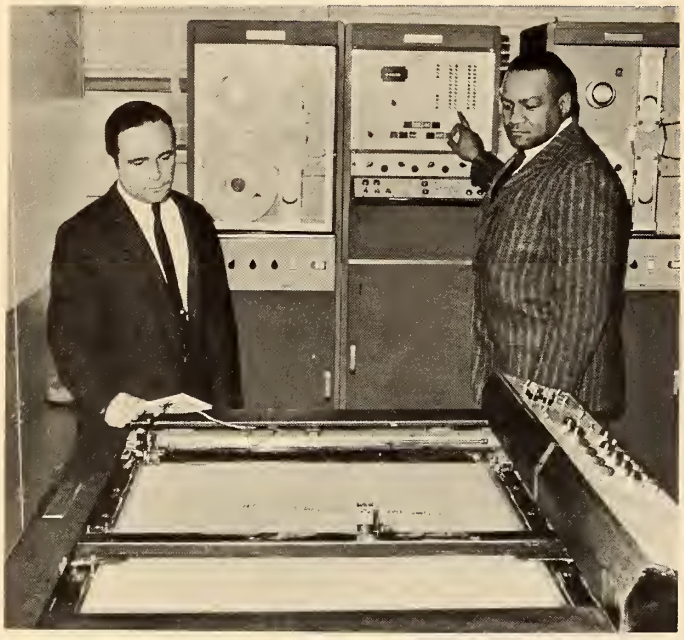
The aim of the NMC's research into weather analysis is to improve the analysis of data required for numerical weather prediction. Research is concentrating on improving analysis within the global belt that extends from latitude 48° N. to 48° S. and includes the tropics. Additional work has been done to incorporate heights into this analysis. Some tests were made with the solution of the balance equation across the Equator. Tests were also conducted to merge tropical analyses with those of the high latitudes.

Numerical Analysis and Forecasting

The approach to numerical weather analysis and forecasting for the tropics involves computing tropical analyses for five pressure levels twice a day and PE barotropic forecasts to 36 hours for two pressure levels once per day on an experimental operational basis. A two-layer PE baroclinic forecast model for the tropical belt was developed and run to 48 hours. Successful merging of the tropical filtered equation barotropic forecast with a high latitude forecast was achieved. A global PE barotropic forecast that ran well to approximately 3 days was also accomplished.

During the last 2 years, the Techniques Development

Laboratory (TDL) of WB performed numerical experiments to determine the optimum meteorological networks for large-scale numerical analysis and forecasting in extratropical regions. The operational analysis forecasting cycle was simulated by data input of varying density configuration and accuracy, and the results were compared with standard analysis and forecasts made from very dense input data.



A computer-run automatic curve plotter analyzing a Northern Hemisphere circulation chart at the NMC, Suitland, Md.

During FY 68, the first experiment of a new series using the Geophysical Fluid Dynamics Laboratory (GFDL) model as a reference atmosphere was run with the barotropic mesh model. The experimental results indicate that for 500-millibar heights, the additional accuracy achieved by reducing station spacing to less than about 600 kilometers is minimal. Results also show that for forecasting the position of highs and lows at 500 millibars, no noticeable improvement occurs if the station spacing is made closer than 650 to 700 kilometers. Attention is now being focused on the initialization problem, especially in relation to the feasibility of frequent cycling of data from nonconventional sources such as satellites and constant-level balloons.

As an ancillary to the large-scale numerical analysis and forecasting problem in extratropical regions, TDL conducted a study to determine optimum meteorological networks in the tropics on the basis of the statistical structure and variability of the tropical atmosphere. Proper station spacing was determined from computations of the power spectra of wind, temperature, and geodynamic heights, and by application of the method of optimum interpolation. During FY 68, various averaging schemes were tried in an effort to reduce the scatter of computer correlations and structure functions, with the 250-kilometer interval producing the most satisfactory results. In FY 69, a synoptic file of upper air soundings in a common format was developed for 370 pertinent stations in the Northern Hemisphere. A computer program was developed to compute spatial correlations of wind, temperature, and height at three levels (850, 500, and 200 millibars) for any 35 of these stations.

Numerical Predictions

Involved in ESSA's research into numerical prediction is the development and use of primitive equations for baroclinic modeling. The ultimate goal of such research is improved forecasts of the state of the atmosphere—in terms of its motion and physical properties. Special parameters forecast by the PE model include wind velocity, temperature, and pressure. In addition, estimates of the presence of clouds and amounts of precipitation are obtained. Work underway during the reporting period used the basic forecast parameters of the model to infer such important small-scale atmospheric phenomena as jetstream turbulence, severe weather storms, and air pollution.

In the past, R&D effort has been directed toward mathematical problems presented by the PE approach. As satisfactory solutions are attained, efforts have shifted to the development of a more comprehensive forecast system that includes exchanges resulting from frictional effects and radiative, latent, and sensible heat processes.

A computer program for the PE model was completed during FY 66; a series of comparative tests was then performed in conjunction with the operational three-level baroclinic model. Because the PE model was an improvement over the three-level baroclinic model, it was introduced into the NMC operational system in FY 66. The PE model now includes modeling of diabatic effects, radiation, latent heat, and exchange of sensible heat with the ocean. Incorporation of these parameters has improved the operational model. The development of a model compatible with global prediction was begun during FY 68. Several different procedures are being developed, and tests will continue to determine which approach will be suitable for operational forecasting.

Extended and Long-Range Predictions

One of the most important studies initiated by NMC involves extended forecasting; specifically, this includes the development, evaluation, and improvement of physical and synoptic methods for the preparation of daily 5-day mean weather forecasts for periods from 3 to 7 days in advance, including the adaptation of extrapolated numerical weather predictions to special problems of extended prediction. Subtasks included in the studies involve developing the physical models for prediction of 5-day mean circulation patterns and evaluating the utility of the latest improved extended numerical predictions.

A number of experiments were made using the NMC operational PE model to forecast to day 6; these experiments suggest possible improvements over the present method of sea level circulation forecasts. Similar promising

evaluations were made of extended forecasts of precipitation, using the numerical model of the GFDL. Detailed evaluations which involve monitoring the scale of operational numerical forecasts were continued during the reporting period. Also, an analog method is under development to assure the consistency of 5-day mean precipitation forecasts.

In an analogous project, the NMC initiated research on ways to apply methods of statistical and synoptic meteorology in the preparation of routine monthly, experimental seasonal, and log-period forecasts of hemispheric weather conditions. A 20-year file of information on the form of long-period averages of seasonal weather parameters over the Northern Hemisphere was used to provide data for the study. The work was coordinated with other research based on a physical and dynamical approach. A study of the month-to-month persistence of temperature for several regions in the United States was completed; work is underway on relating various types of daily weather statistics to the mean circulation, with the objective of increasing the utility of the monthly and seasonal forecasts.

Another research project conducted by NMC was a study to provide quantitative guides to the preparation of extended and long-range weather forecasts in the form of analogs, composite charts, weather types, and other kinds of statistical climatology drawn from a historical file of 5-day and monthly mean hemispheric circulation and weather charts. Historical data were processed in special forms and stored on magnetic tapes and in catalogs. Methods were developed for rapidly selecting analogs by machine methods, and composite chart atlases were prepared showing the probability of weather in different regions as related to circulation anomalies in other remote regions, both concurrently and at various time lags. A series of composite daily and concomitant weather charts was also developed. A composite chart method for relating 5-day mean circulation (wind) anomalies in one part of the Northern Hemisphere with those in any other part was completed during the reporting period.

The NMC also initiated research on an extended forecasting study whose objectives were: (1) to use statistical techniques to specify the weather from extended-range circulation forecasts and to predict long-range circulation and weather patterns from initial data; (2) to evaluate the skill of new and operational forecast techniques; and (3) to assist forecasters in stating their predictions and probabilities. Such statistical methods as stepwise multiple regression, principal components, discriminant functions, and time-series analysis were employed. Evaluation of new (physical or statistical) and existing operational forecast techniques required comparisons of their accuracy to forecast control and past performance and to the analysis of the nature of forecast errors. "Forecasters' confidence" tests, Bayesian techniques, and multiple regression and discriminant function analysis were used to synthesize verification experiments and forecasters' judgments and to produce probability statements. A computer run of the historical data was used for these tests.

Special procedures were devised and utilized to evaluate 72-hour temperature forecasts. A test of the NMC's PE model which extended the ranges and the forecasters' ability to predict weather was designed, performed, and verified. Spatial variations in local height regression equations were devised for 30-day forecasting; one set was placed into operation. New averaging intervals were designed for kinematic tendency calculations in both 5- and 30-day forecasting to permit separate long- and short-period changes in the circulation.

The NMC began research into the development of a cloud and precipitation forecast model in FY 67. The principal aim was the development of more accurate forecasts of cloudiness and precipitation. A subordinate goal is to provide information on latent heat generation in the atmosphere. Experience gained with the present NMC precipitation model was used in the development of the new approach. Moisture was considered as a single layer in the lower half of the atmosphere. The criterion for condensation was based on the mean relative humidity in the layer.

Work in FY 69 has led to the development of a three-layer precipitation model. The moisture that was carried as a single layer has now been distributed among the three bottom layers of the PE model. The criterion for condensation, which is the calculated mean saturation vapor pressure, is now computed for each layer. In addition, interaction between layers has been established.

Experimental Prediction

Using its own nine-level model, the GFDL has been preparing 2-week forecasts for biweekly periods since March 1, 1965. These results were compared with independent predictions for each hemisphere to assess interhemispheric interaction. Two-week predictions with the nine-level hemispheric model are also being made for six January cases—1963, 1964, 1966, 1968, and two periods in 1967. The results were verified against observation in considerable detail.

To assimilate observational data with minimum shock to the 2-week forecast and with maximum extraction of information content, a four-dimensional analysis technique was used to precondition the data. A 4-day span of data was used to synthesize a set of initial conditions. The interpolation-extrapolation in four dimensions was made by using the most detailed version of the nine-level high-resolution hemispheric model. To evaluate their quantitative significance to the initial condition configuration, the relative importance of five variables—surface pressure, vertical velocity, water vapor, boundary layer temperature, and boundary layer wind—has been tested. Experiments showed that the predictions are the same after about 2 days, irrespective of the initial values of these quantities.

Other tests were made to evaluate the effects of internal viscosity, surface friction, condensation criterion, and small-scale moist convection. Certain special phenomena, such as the breakdown of the stratospheric polar-night vortex, have been successfully simulated and studied. To increase the accuracy of the simulation and to include the possibility

of sudden warming, an 18-level hemispheric model was used. In addition, experiments using both the observed sea-surface temperature and a hypothetical distribution of anomalies were made to determine how quickly and in what way the effects of the anomalies became apparent. Results should indicate whether routine observations and forecasts for the upper layers of the oceans must continue.

The NMC, in conjunction with the Department of Meteorology at the Massachusetts Institute of Technology (MIT), studied solar variations and atmospheric circulation. Objectives of the study were to describe, understand, and forecast the long-period changes of atmospheric circulation and weather, with emphasis on such internal and external factors as index "cycles" and solar activity. A university team provided support to the WB by preparing statistical, synoptic, and solar weather approaches to long-range forecasts.

The approach to this study involved processing mean weather and circulation data, including the 62-year series of seasonal mean Northern Hemisphere pressure charts. Long-period trends and oscillations, including variations related to different phases of the sunspot cycle, were researched. Internal interrelationships of weather and circulation, both simultaneously and with different time lengths, were sought through statistical procedures.

Experimental seasonal weather forecasts were prepared for the United States based on solar-weather analogs. Statistical methods, employed to predict summer temperature in the United States, were also used in an investigation of large-scale heat transfer processes and fluctuations of sea-surface temperature in the North Pacific Ocean; the methods were also applied to synoptic and statistical work on the specification, explanation, and forecasting of large-scale patterns of persistent drought and wetness in the conterminous States and Alaska.

Atmospheric General Circulation

The NMC, in cooperation with the MIT, sponsored a study during the last 2 years to investigate the hypothesis that the tendency of anamolous atmospheric circulations to persist over extended time periods may be caused by feedback from underlying land or water surface, and to discover the physical mechanisms and processes that could have helped form such persistence. (The GFDL is also making models and extensive computer studies of ocean-atmosphere coupling.) The procedures used in this study consist of establishing and solving numerically two separate systems of equations which are designed to resemble in their principal features those equations that govern the behavior of the atmosphere. One system considered the feedback effects of the underlying surface; the other did not. Two separate systems of equations were formulated, and particular solutions were obtained for periods extending a few weeks. Work is underway on extending solutions for periods of 6 to 12 months or longer to provide more conclusive evidence of persistence.

Numerical simulation of the seasonal variation of the thermal and dynamical structure of the troposphere-stratosphere system was conducted by the GFDL, using the global general circulation model with the actual distribution of mountains, oceans, continents, and the observed seasonal variations of sea-surface temperature. The influences of seasonal fluctuations of solar insolation and the hydrologic components on the atmosphere circulation were of particular concern in the simulation.

To resolve the synoptic scale disturbances of the tropics, a grid system with high resolution was chosen using a domain of limited longitudinal span. Major objectives of this numerical modeling experiment are to examine the role of convection in maintaining tropical disturbances and the Intertropical Convergence (ITC) Zone, and to investigate the interaction between the tropics and midlatitudes.

Numerical simulation of the evolution and maintenance of water vapor and that of ozone in the stratosphere was also performed. For this study, an 18-level model with high vertical resolution was used. Mechanisms for the exchange of various quantities (heat, momentum, water vapor, and ozone) between the stratosphere and troposphere were determined. The nature of dynamical-photochemical-radiative coupling in the model stratosphere was analyzed so that the degrees of freedom of the model were gradually increased.

Because of the very long relaxation time of stratospheric circulation, investigations into economical methods for approaching quasi-equilibrium in numerical simulation experiments were conducted. In addition, two general circulation experiments were run with a global model and without the effects of mountains. The comparison between the two experiments indicated the role of mountains in maintaining the general circulation of the atmosphere. The climatic state of the global circulation was represented by the zonal mean state of the atmosphere and by such statistical quantities as the amount of eddy kinetic energy, eddy transfer of heat, and angular momentum. These quantities are the integrated measures of the intensity and structure of individual synoptic scale disturbances. The object of the investigations was to integrate the closed system of equations which express all the climatological quantities as time-dependent variables.

Upper Atmosphere Investigations

The NMC has conducted upper atmosphere investigations whose primary objective is the study of the structure, circulation, and energetics of the stratosphere and neighboring layers. Subordinate objectives were to apply the results to improve stratospheric map analysis, and to describe the variable atmospheric environment of supersonic aircraft and reentry vehicles. The investigation into these altitude regions is of increasing theoretical and practical importance to the mission of the WB.

Objective analyses techniques were used to improve computer-analyzed 100- through 10-millibar charts and to produce 5-, 2-, and 0.4-millibar charts from rocketsonde reports. These charts and vertical cross sections are utilized for continued study of the origin and nature of stratospheric warmings, for which the NMC serves as a World Warning Agency. The theoretical aspects of the investigations in-

clude the description of the role of the stratospheric energy cycle in relation to available tropospheric energy. Detailed investigations into reporting irregularities and disparities between rocketsonde and rawinsonde reports have led to corrections to account for day-night temperature differences and characteristics of different instruments used.

General Circulation of the Ocean-Atmosphere System

To investigate the role of the ocean's circulation in maintaining the climate and that of the atmosphere in maintaining the dynamics of the ocean, a numerical simulation of the thermal and dynamical structure of a joint ocean-atmosphere system is underway by GFDL. Global general circulation models of the atmosphere and of the ocean, developed separately, were combined for the simulation. Because of the extremely long relaxation time of the deep oceanic circulation, efficient methods for approaching a quasi-equilibrium are in development. Numerical simulations were made for various idealized configurations of continent and ocean to provide an insight into the relation between climate and large continental landmasses.

Simulations have been performed for the Indian Ocean, successfully predicting the striking changes in the Somali Current resulting from seasonal monsoon changes. For time variation studies of the structure of the joint system, seasonal variations of solar insulation were taken into consideration. Numerical simulation of the seasonal variation of the thermal structure, general circulation, and hydrologic cycle was the main objective of those studies. The quasi-equilibrium state, which is obtained for the annual mean insolation, was chosen as the initial condition for this numerical integration. By integrating the joint system for an extended period, a study of their time evolution for periods longer than 1 month or 1 year can be undertaken, and information on the long-range evolution of climate can be obtained.

The NMC is also involved in studies that concentrate on the interrelationship between the atmosphere and oceans, particularly in the prediction of large-scale atmospheric evolution. The aim of one of these studies was to apply those physical principles governing the evolution of the atmosphere and oceans to the prediction of sea temperature, storminess, and weather changes for periods of 1 month or longer. This project involved the study of the energy balance of and energy exchange between the atmosphere, land, and oceans in relation to anomalies in ocean temperature, snow, and ice cover. Acquired knowledge was applied to physical models for numerically predicting the evolution of monthly mean states of the atmosphere and ocean.

A study, concluded in FY 67, of the 1961–1966 Northeastern U.S. drought led to a more general study during the last 2 years of seasonal precipitation for States in this region in relation to patterns found in other States.

New emphasis was placed on ocean-atmosphere interactions over the Pacific Ocean. Tests and evaluation on numerical models for predicting mean rainfall and temperature in the atmosphere and ocean for 1 month in advance were conducted. An improved numerical model which could incorporate the mean water budget of the atmosphere, horizontal heat transfer in the atmosphere and ocean, and reflectivity of the earth's surface was developed.

Basic Geophysical Fluid Dynamics

A finite difference model of annulus circulation has been set up by GFDL to yield solutions to the three-dimensional Navier-Stokes equations in polar coordinates for laminar fluid flow. The fluid motion is driven by rotation and lateral temperature differential. The model was devised to describe and examine geophysical fluid modes in pure and isolated form, and at present is being used to analyze such basic annulus dynamical modes as vacillation. Because the model system is fully three-dimensional (the hydrostatic assumption is not made), the system can be used to model other geophysical phenomena in which vertical motion is large. Such an application was made to study the genesis and evolution of frontal systems as a supplement to analytical studies.

Numerical experiments were run with and without a mean wind shear to simulate dry convection with height. Initial efforts were directed toward the simulation of laboratory experiments. Subsequent numerical experiments were directed toward simulation of convection in the earth's boundary layer. A primary goal in this study was to gain an understanding of the breakdown of laminar convection into turbulent convection with increasing Rayleigh number. In studies of thermal convection equilibrium with rotation, the fundamental processes in convection were analyzed, including the roles of Ekman layers, variable fluid parameters, and finite-amplitude effects between rigid boundaries in uniform rotation.

The two-dimensional Boussinesq approximation was applied to the steady Navier-Stokes equations, and the numerical simulation is quantitatively compared with analytic theory and high-precision laboratory data. Frontal dynamics were evaluated by studies of frontal genesis and instability through linear stability and analysis. The energetics involved were investigated by analytic and numerical techniques. The growth of surface water waves and the subsequent sea-air interaction when a turbulent shearing flow in the air passes over a body of water initially at rest were also being studied. The problem was treated numerically with the goal of ultimately attacking the nonlinear, finite-amplitude case.

Observational Studies

The GFDL conducted a series of observational experiments involving studies that used aerological data from May 1958 to April 1963. The atmospheric energy cycle for 10-degree-wide latitude belts between 10° S. and 90° N. and its annual variation were studied using 5 years of radiosonde data. The total energy was subdivided into its internal, latent, potential, and kinetic components. By calculating the vertically and zonally integrated convergence of each form of energy into these latitude belts by mean meridional and by transient and standing eddy circulation, GFDL scientists were able to determine (as a residue) the rate at which the actual energy conversions take place in

the atmosphere as a function of latitude and season. A water balance study determined the mean monthly values of vapor flux, vapor flux divergence, runoff, evapotranspiration, and combined surface and subsurface storage change over the North American continent and its major drainage areas. The vapor flux was partitioned into contributions from standing eddies, transient eddies, and mean meridional circulations. The characteristics and seasonal variations of the three modes of transfer were evaluated on a mean monthly basis.

Observational Stations

Work by the Equipment Development Laboratory (EDL) of the WB continued during the last 2 years on an intermediate automatic weather station, the AMOS (Automatic Meteorological Observing Station) III–70. This project is intended to develop an automated equipment complex to provide both manned and unmanned meteorological observations. The AMOS III–70 frees the observer on duty for more complex tasks and also allows observations when no observer is present. The design of the AMOS III–70 permits modularity, high reliability, ease of maintenance, and miniaturization. The basic unit contains modules designed to report temperature, dew point, wind speed, wind direction, altimeter setting, precipitation accumulation, and precipitation occurrence.

During FY 68, modifications to the grounding system between the basic unit and sensors were completed and noise levels reduced. A sensor simulator was also fabricated and used to test the AMOS III–70 over a wide range of parameters. Except for the precipitation occurrence sensor, the basic station successfully completed environmental testing in FY 69. The basic system was adjudged fully suitable from an engineering standpoint, and work was initiated to prepare specifications for operational procurement.

Another phase of the AMOS III–70 project involved the development of the Manual Input Device to provide an observer with a way to add his observations of ceiling, visibility, weather obstructions to vision, and sea level pressure to the AMOS III–70 message for transmission. In FY 70, two manual input prototypes, which allow data input from either a local or remote location, will be completed. A method now under development adds a "remarks" capability to the Manual Input Device.

Weather Sensors

The EDL has maintained research on the development of components for surface observing systems, specifically improved weather sensors. The Laboratory has conducted research into the development of a set of basic sensors (pressure, temperature, dew point, and wind) which can operate unattended for long periods of time in remote locations where commercial power is not available. These sensors will be evaluated for use with a Remote Automatic Meteorological Observing Station (RAMOS). In FY 69, development work leading to a RAMOS included an analysis of commercially available amplifiers to determine their reliability, accuracy, and long-term stability. Particular emphasis was placed on amplifiers with low-power consumption and good temperature reliability. With these amplifiers as basic building blocks, new sensors will be developed to measure the basic meteorological parameters of temperature, dew point, pressure, and wind. In FY 70, an engineering model of an Electronic Altimeter Setting Indicator will be developed under contract.

As part of sensor research, EDL conducted development work for an improved hygrothermometer. During FY 68, all circuitry for the aspirated hygrothermometer was designed and components received. Compatibility with the AMOS III–70 was accomplished with minor modifications to temperature and dew point boards. Work during FY 69 centered on exploratory development of a small package including thermometer, hygrometer, aspirator, pulse duration modulation (PDM) output, and analog current output. Fabrication and assembly of an experimental model of an all-electronic lithium chloride hygrothermometer was completed in FY 69.

In a related effort, EDL completed the development of special wind sensors and data processors that simplify and correctly measure and compute mean wind and wind fluctuations. This project included: (1) the design of dynamically correct rotating cups and vane; (2) the design of a wind vector component generator; and (3) the design of analog data processors to compute wind statistics. During FY 68, the first design of a transducer to convert directly from cup anomometer and vane motion to orthogonal components was completed and fabricated. The experimental cups and vane were developed in FY 69, along with a frequency analog transmitting-and-receiving indicating system.

Meteorological Statistics Studies

Research was conducted by the Air Resources Laboratory (ARL) of RL on the application of mathematical statistics to those atmospheric science problems concerned with the understanding, prediction, or ultimate control of the physical processes of the atmosphere.

During FY 68, research focused on the influence of the lunar-solar gravitational tide on various atmospheric phenomena, including tropical cloudiness, certain quasi-biennial oscillations, and general circulation. Considerable evidence was found for an apparent latitudinal adjustment in surface pressure—represented by the zonal index—in response to variations in the gravitational tides; the effort to develop and understand these relationships continued.

Two solutions to statistical-meteorological problems of general interest were formulated: (1) a stepwise multiple regression procedure for obtaining predictors for a nonstationary time series; and (2) a new correlation statistic for testing the association between two time series, each containing serial correlation.

In FY 69, research continued on the tidal relationships to sea level pressure distribution, with new studies underway on the diurnal variation in types and amounts of tropical clouds within the tidal framework, on the relationship between coastal rainfall and general circulation features, and on a scheme for long-range forecast of rainfall at a single

station based on certain surface features for dates suggested by tidal relationships. As needs arose, cloud seeding experiments were designed and analyzed.

Upper Air Systems

The SDO over the last 2 years has conducted several efforts aimed at automating data processing associated with upper air observations. Through its TDL, formulas and procedures were derived for use in computers in place of human data processors. During FY 68, considerable effort was devoted to developing special procedures for use when input data were missing or doubtful. In FY 69, TDL devised specific computer procedures for the numerical calculation of precipitable water, a parameter used in making quantitative precipitation forecasts.

The EDL also conducted development work aimed at semiautomating computations of rawinsonde data to reduce human error and manpower requirements. A radiotheodolite angle/range digitizer was designed and developed to accept raw analog data from the standard WB radiotheodolite wind-tracking equipment and to convert it to a digital form, using the Baudot code for teletypewriter transmission. The angle/range digitizer is currently undergoing test and evaluation; preliminary results are very encouraging. To take advantage of commercially available time-sharing computers, a major design change is being made in the digitizer to produce output data in ASC II code—the standard code employed by such systems.

Another related effort conducted by EDL in FY 69 is aimed at taking advantage of locally available time-sharing computers to make calculations that have traditionally been done manually by two men. Accordingly, rawinsonde computational and error-checking programs were developed that employ a conversational mode for input. This method enables the computer to query the observer when questionable data have been entered. The system is designed so that the observer still encodes the messages for transmission, during which time he can also check on the reasonableness of the computer's output. The system developed requires only one man to take an upper air observation. Operational tests were conducted in early 1969 at J. F. Kennedy International Airport's upper air station; minor adjustments to the procedures were made as a result of the tests. The WB is now implementing this technique on an operational basis at a number of upper air stations.

In a major contribution toward development of the next generation upper air data acquisition system, the Systems, Plans, and Design Division (SPDD) of SDO completed a Systems Engineering Study of Atmospheric Measurements and Equipment (SESAME). Systems concepts and functional equipment specifications were derived for the acquisition system which will be designed to provide macroscale, mesoscale, and near-microscale upper air data.

The SESAME project involved a comprehensive survey and forecast of potential upper air measuring techniques, including satellite-borne and ground-based indirect sensors. The results of this survey showed that only balloon-borne instruments would meet the data requirements for all scales of motion during the 1970's. An objective cost effectiveness model—a linear polynomial with variable weights—was developed to compare competing upper air systems. A trade-off analysis was made using the cost effectiveness model on a number of wind-finding techniques such as radio distance finding, navigational aids (NAVAID), and radar. The resultant analysis showed that a balloon-borne package using a NAVAID approach—long range aid to navigation (Loran-C) and Omega—for wind finding was the most cost effective system for upper air measurements in the 1970's.

The development work by T&EL on the next generation upper air system involved testing and evaluating an Electrolytic Hydrogen Generator for use in inflating upper air balloons. A 9-month test period, completed in FY 69, showed that this Generator is capable of producing sufficient hydrogen to meet the needs of any WB upper air station. A cost comparison with other hydrogen sources showed that the Electrolytic Hydrogen Generator would not be economical at most facilities in the conterminous States; however, considerable savings could result if it were used at arctic and tropical stations.

During the last 2 years, the EDL was also responsible for developing new concepts for upper air measurements to improve the WB's capability for describing the state of the upper atmosphere. This study included developing a system to use the NAVAIDs—Loran-C and Omega—for measuring winds aloft, and also making a feasibility investigation into the use of several remote-sensing techniques.

To develop a winds-aloft measuring system utilizing Loran-C and Omega, EDL first developed several Loran-C and Omega receivers which were then added to the traditional radiosonde flight packages. Supporting ground equipment and engineering services for the new systems were obtained from a contractor. As a part of this effort, a Loran-C time difference digitizer for use with the Loran-C tracker was fabricated and delivered to EDL in FY 69. Experimental flights were conducted with these NAVAID systems in FY 69 at the National Aeronautics and Space Administration's (NASA) Wallops Island, Va., Station to compare the accuracy of Loran-C and Omega with wind measurements from the Weather Bureau Radiotheodolite (WBRT) and Ground-based Meteorological Detector (GMD) systems and from the FPS-16 precision-tracking radar. These comparison flights showed that Loran-C is capable of measuring winds more accurately than the WBRT system that is presently in widespread use, while Omega provides an accuracy comparable to that of the WBRT. The design and analysis phase for the Loran-C and Omega wind-finding systems will be conducted in FY 70, and experimentation will be continued to determine the ultimate capabilities and limitations of the techniques, especially the geographical coverage.

The EDL also investigated the area of remote sensing for upper air measurements because such techniques have potential for eventually reducing the cost of upper air observations. Three different techniques were considered by EDL for potential WB use: (1) passive microwave techniques for measuring temperature profiles; (2) an acoustic radar for determining humidity profiles; and (3) Raman

backscatter for measuring the vertical profile of water vapor. In FY 69, a contract investigation was initiated by Sperry Rand Research Center to determine the microwave remote-sensing technique's altitude capability and its sensitivity to adverse weather conditions. With regard to the acoustic radar studies, EDL had procured all the hardware necessary to measure ambient noise and to create a sonic beam by the end of FY 69. Preliminary studies of the Raman scattering technique, based on theoretical considerations, have shown that the technique may only work in a clear atmosphere and would be seriously disturbed by clouds, fog, and even haze.

PUBLIC WEATHER FORECASTS

Service Programs

The objective of the public weather forecasts program is to provide daily weather forecasts and to issue advanced warnings of adverse weather conditions—such as blizzards, heavy snows, cold waves, ice storms, hazardous driving conditions, frost, storms, tides, high winds, and sandstorms —to the general public through the distribution facilities of the mass media.

Forecasting

Public weather forecasts and warnings are prepared at Weather Bureau Forecast Offices (WBFO) serving a network of local Weather Bureau Offices (WBO). Certain of these WBFOs serve as Warning Coordination Centers issuing special warning bulletins to the press, radio, television, Red Cross, State police, civil defense units, and other interested groups to alert all concerned public service organizations on impending hazardous conditions.

Each WBFO develops state forecasts every 6 hours on the general weather conditions expected within its zone of responsibility—normally a single state, or a large portion of one or several small states—for 48 hours into the future, using guidance products furnished by the National Meteorological Center (NMC). Detailed weather forecasts for zones of 5,000 to 15,000 square miles in extent, having homogeneous atmospheric conditions, are also prepared by the WBFO.

The local WBOs take weather observations for their area of responsibility; they also prepare warnings based on known weather hazards and localized forecasts based on the guidance of WBFO state forecasts. Localized forecasts or adaptations of state or zone forecasts take into account the climatology, topography, and general weather peculiarities of the limited areas to which they apply.

Dissemination

The WBOs throughout the Nation serve the public in their communities and surrounding areas by providing weather reports, advisories, forecasts, warnings, and general weather information. These WBOs disseminate forecasts similar in content to WBFO zone forecasts except that the areal coverage extends to a major town or city and its suburbs, generally to a radius of 25 miles. Local WBOs also issue short-range (up to 3 hours) warnings before or during severe local storms.

Weather information is distributed locally by the press, radio, and television over public service teletypewriter circuits. The public may also receive information directly from automatic telephone-answering devices, over continuous very high frequency (VHF) radio facilities that transmit weather reports, through personal telephone calls, and by personal visits to the WBO. Large numbers of forecasts, warnings, and other pertinent weather data are disseminated to the public by direct radio broadcasts from the WBO.

As part of the continued implementation of the Nationwide Natural Disaster Warning (NADWARN) System started in FY 67, VHF radio-transmitting facilities are being increased at more WBOs in an effort to expand the dissemination of weather warnings to the public. This VHF service has led to a more rapid, efficient dissemination of warnings on tornadoes, floods, hurricanes, and other severe weather hazards to Federal, State, and municipal authorities concerned with public safety. Ultimately, such VHF service will be extended to each of the country's major metropolitan areas.

Research and Development Programs

The objective of the R&D program for public weather forecasts is to provide a basis for improved local service. Two approaches are pursued. In the first approach, the computer-processed products of large-scale numerical-dynamical prediction models are refined to provide local forecasts of specific weather elements. In the second approach, new prediction techniques utilizing statistical, climatological, and synoptic methods are developed for use by field forecasters making the local forecast.

Prediction Techniques

Although there are separate R&D programs in public weather forecasts, many of the R&D programs funded in Basic Weather Services also support the public weather forecasts. One of the principal objectives of this support is to increase the use of numerical methods for both extended and short-range forecasts.

During the reporting period, the WB's Techniques Development Laboratory (TDL) and Systems Development Office (SDO) conducted research involving several numerical prediction projects to improve public forecasting through the extension of NMC products to field forecasters.

Specifically, one TDL project was initiated to develop techniques and programs for automated prediction of surface temperatures and pressures. As a result, a completely automated system of predicting surface maximum and minimum temperatures 12 to 60 hours in advance at 131 U.S. cities has been developed, tested, and put into operation on a twice-daily basis.

Another TDL project was started which adapted existing NMC large-scale numerical models to a smaller scale to

provide 3- to 18-hour predictions of precipitation within a zone of about 50 miles in diameter. From this project, subsynoptic advection model (SAM) forecasts were prepared and have been available since early 1968 on a twice-a-day basis over RAREP (Radar Report) and Warning Coordination (RAWARC) circuits to 79 Eastern States cities. In October 1968, SAM forecasts were placed on a four-panel graphical chart sent to WBFOs twice daily. These charts display the probability of measurable precipitation in 6- and 12-hour periods, the conditional probability of freezing precipitation, the sea level pressure, and the 1,000- to 500-millibar thickness layer.

Still another TDL project was conducted to improve and automate the nationwide forecasts of probability, timing, and amount of precipitation for public and hydrologic use. Conditional probabilities of precipitation were computed for 108 cities in the United States. These forecast aids include the unconditional probability of precipitation for 6-, 12-, and 24-hour periods by months; the conditional probability by season as a function of precipitation during the previous period; and the conditional probability of various amounts if precipitation occurs.

The TDL also developed precipitation forecasting techniques and methods for selected U.S. geographical regions during the last 2 years. Physical, statistical, synoptic, and dynamic procedures were combined to derive new and improved techniques relating precipitation to atmospheric circulation parameters. For example, an automated system was developed for predicting quantitative precipitation (in eight categories) during the winter season in nine river basins of the Tennessee-Cumberland River Valley for 1 to 3 days in advance. These objective forecasts have shown greater skill than subjective forecasts for 48 hours, but not as much skill as those for 24-hour projections.

Field Forecasting

ESSA's WB has been conducting various R&D projects to provide the local WBOs with weather analyses and forecast guidance to meet their specific local requirements, including predictions of rain, snow, and fog for local aviation and hydrologic forecasts. These forecasts are adaptations of state and zone forecasts.

The WB's TDL continued its efforts to develop improved techniques for short-period localized forecasting. Efforts were directed toward techniques to forecast are probability of snow occurrence, amount of snowfall, and discrimination between rain and snow for major cities along the U.S. east coast. A synoptic and statistical method was employed, based on the assumption that perfect prognostic maps of pressure are available to the forecaster and that the problem involved determination of the weather event from pressure field or other information.

Results from the Northeastern States snow prediction study, performed under contract by New York University, indicate that simple, reliable techniques for predicting onset time and depth of snow or for discriminating between rain and snow are not yet available. However, certain statistical and synoptic information can assist the forecaster in making local snow decisions. Local forecasters can predict local onset time of snow by using the distance-time graph to determine the principal direction octant by the maximum correlation coefficient method and the approach speed of precipitation from the linear regression coefficients. The study also found that the boundary layer potential temperature produced by the primitive equation (PE) model exhibited skill in the discrimination between rain and snow.

Another TDL contract study with the Travelers Research Corporation was conducted to relate heavy snow occurrences along the eastern seaboard to the position of the 850-millibar cyclones. Useful snowfall patterns were obtained for various storm types.

The TDL also supported a contract study by the University of Hawaii involving the improvement of objective techniques to permit forecasting up to 24 hours in advance of the onset time and to determine location of heavy rain in that State associated with disturbances of synoptic and subsynoptic scale. This project involved investigations of the 24-hour rainfall accumulation patterns associated with various frontal positions in the vicinity of Hawaii. Included in the study were possible correlations of thunderstorm occurrences with "wet," "dry," and moderate fronts. It was also found that rain from decaying tropical storms is enhanced by cyclonic activity in the middle and upper westerlies.

In FY 69, TDL also developed charts for 35 stations west of the Continental Divide; these charts give the 12-hour probability and average amount of precipitation as a function of location and intensity of low centers at 850, 700, and 500 millibars. The charts were developed for use at local stations to give the field forecasters an objective tool for predicting the probability of local precipitation.

As an aid to the local forecaster making predictions of visibility, fog, and low-level wind shear during the critical early part of the forecast period, the TDL conducted research on a project to develop techniques for analysis and short-period forecasts in the atmospheric boundary layer. This project involved the use of a mesoscale synoptic approach which utilized 5 years of surface, tower, and radar data from the Washington, D.C., Mesonet as well as from other sources. A real-time test of the visibility forecasting techniques developed under this effort was conducted at the Washington WBFO from September to November 1968. The two objective techniques tested performed about as well as did the field forecasters.

As part of the continuing efforts to help local forecasters, the TDL launched a study of the statistical relationship between actual weather variables and parameters forecast by numerical models. In FY 69, 3-hourly values of observed weather variables—including ceiling, visibility, total sky coverage, weather, dew point, wind, temperature, and precipitation amounts—were obtained from the National Weather Records Center (NWRC) at Asheville, N.C. These parameters will be related to the output of numerical models. A total of 254 cities in the 50 States and Puerto Rico were selected for the study.

HURRICANE AND TORNADO WARNINGS

Service Programs

The aim of the hurricane and tornado warning programs is to furnish adequate warnings in sufficient time to enable the public to make necessary preparations for safeguarding life and property.

Hurricane and Severe Storms Warning Preparation

Staff personnel in the seven offices of the WB's Hurricane Warning Service maintain a close watch on areas of potential or incipient tropical cyclones and produce and issue advisories or bulletins for the general public, disaster and rescue agencies, and salvage operations in threatened areas. These offices include the National Hurricane Center (NHC) in Miami, Fla.; Eastern Pacific Hurricane Center and Central Pacific Hurricane Center in San Francisco, Calif., and Honolulu, Hawaii, respectively; and Hurricane Warning Offices in Boston, Mass., Washington, D.C., New Orleans, La., and San Juan, P.R.

The NHC provides hurricane forecasts for the Atlantic and gulf coast areas and is responsible for the Atlantic Hurricane Warning Service including the supervision of warnings issued in Boston, Washington, New Orleans, and San Juan. All warnings issued for those areas are based on large-scale surface and upper air analyses and forecasts, prepared every 6 hours by the Regional Center for Tropical Meteorology (RCTM) at the NHC. The San Francisco and Honolulu Centers provide forecast and warning services for the eastern and central Pacific, respectively.

The hurricane advisories and bulletins prepared by the Centers and Warning Offices for the general public contain information on the position, intensity, direction and rate of movement, areas under watch or warning, areas under flood and tornado threats, precautions to be taken, and anticipated coastal effects of the storm. Special marine, aviation, and military advisories are prepared to give pertinent information to these special users and to the military services.

A special, cooperative hurricane-reporting network is maintained along the Atlantic and gulf coasts of the United States. At locations approximately 50 miles apart, the WB provides volunteer observers with standard weather-measuring equipment to obtain accurate readings of wind speed, wind direction, and barometric pressure for transmittal to the nearest Weather Bureau Office (WBO). Special hurricane observations are received from the Cooperative Coast Guard Network. Hurricane surveillance is also maintained by use of Applications Technology Satellite (ATS) and Environmental Survey Satellite (ESSA) spacecraft.

Tornado and Severe Local Storms Warning Preparation

The National Severe Storms Forecast Center (NSSFC) at Kansas City, Mo., prepares and releases public watches for severe thunderstorms and tornadoes in the United States. These public watches are released to WBOs in affected areas for dissemination to the public. The local WBOs also originate tornado warnings on the basis of actual tornado sightings or radar indications and alert other WBOs in the path of the approaching storm. The Severe Local Storms (SELS) forecast unit of the NSSFC also prepares Aviation Severe Weather Watches for distribution to the aviation industry.

Dissemination

Warnings of both hurricanes and tornadoes are given immediate and widespread distribution by the WBOs in the affected areas through all available means of communication.

Hurricane forecasts and warnings are disseminated by teletypewriter, radio, telephone, newspaper, television, and Government communications facilities. Forecasts and warnings are available simultaneously at all WBOs on the Atlantic and gulf coasts by special hurricane teletypewriter circuits. Local WBOs are responsible for releasing advisories and bulletins, issuing statements on the local effects of the hurricane, and distributing hurricane material for use in public education and preparedness information programs.

Public watches on tornadoes and severe thunderstorms and warnings of such severe weather phenomena are disseminated in the affected area by the local WBOs through radio, television, telephone, and teletypewriter facilities. Aviation Severe Weather Watches are also disseminated to the WBOs, Federal Aviation Administration (FAA), and military offices in affected areas.

Research and Development Programs

ESSA conducts R&D programs on hurricanes and other severe cyclonic storm circulation to acquire increased knowledge of these hazardous storms; to apply this knowledge to improvements in techniques for storm detection, forecasts, and warnings; and to develop possible means of storm modifications.

ESSA's hurricane and severe storms R&D program efforts are initiated through research activities of the RL's National Hurricane Research Laboratory (NHRL), with supporting research in mathematical simulation augmented by cooperation with another RL component, the Geophysical Fluid Dynamics Laboratory (GFDL). The WB's NHC utilizes products prepared by the NMC and conducts research studies into the problems of detection, development, structure, modification, and forecasting of hurricanes; in addition, the NHC has been studying techniques to forecast hurricane motion and investigating and making recommendations on how to improve warnings to the public so that they will react and take the proper precautionary measures.

In hurricane research, both RL and WB conduct a broad-based program on basic and applied research in techniques development for hurricanes and related tropical phenomena. Such programs will lead to improved forecast and warning services and may provide a possible means of diminishing the intensity of these severe tropical storms. The research program includes investigation of the structure, circulation, and energy sources of hurricanes and other tropical storms using data obtained by specially instrumented aircraft, weather satellites, and conventional weather observation

networks. Special studies are being conducted to provide insights into the nature of tropical disturbances; digital computers are used to develop mathematical models which simulate the atmospheric conditions of these tropical disturbances. Based on this fundamental work, broad programs of R&D are being carried out to improve the techniques available to the weather forecaster for predicting the formation, motion, intensity, and structure of individual hurricanes and other tropical storms.

ESSA conducts R&D programs to obtain an improved understanding of tornadoes, squall lines, thunderstorms, and other severe local storms and to develop improved methods for early detection, identification, and prediction of these severe local weather phenomena. These efforts give direct support to the severe local storms warning program and provide knowledge needed in the weather modification program for the development of methods to modify severe storms.

To conduct these programs, data are obtained from a high density network of surface meteorology stations, an instrumented tower, rawinsonde releases in urban areas, conventional and Doppler weather radars, atmospheric electricity field monitors, and meteorologically instrumented aircraft.

Local severe storms have been studied using time-lapse film pictures from ATS spacecraft. It is planned to make these pictures available in real-time to the NSSFC in the spring of 1970 as a pilot project to apply geostationary satellite technology to the severe local storms warning program.

From the data collected, new information is obtained on the structure and dynamics of severe local storms, providing a basis for the development of improved forecasting and warning techniques.

Advanced techniques are developed for probes of the atmosphere by conventional and Doppler radars, and for the processing, displaying, and transmitting of information obtained by these techniques. Weather radar studies are conducted to interpret radar information in terms of the characteristics of atmospheric phenomena.

Several research projects are conducted through the National Severe Storms Laboratory (NSSL) at Norman, Okla. A special cooperative severe storms network of 56 surface meteorological stations and a 1,500-foot instrumented tower, located in an adjacent area, collect the data for the research conducted at RL's Wave Propagation Laboratory (WPL) on the development of a Doppler radar system to expand the capabilities for studying air motions associated with storm systems. Other research work includes the system finding and analysis activity, severe storms measuring equipment development, and forecast technique development.

In direct support of the severe local storms warning program, a systems planning analysis was conducted; special equipment and severe storms forecasting techniques were developed by the WB's Systems Development Office (SDO). The systems study was required for proper planning of improvements to the warning program; the study included an analysis of user requirements and an evaluation of alternative methods of providing required services to the public.

Hurricane Forecasting and Prediction

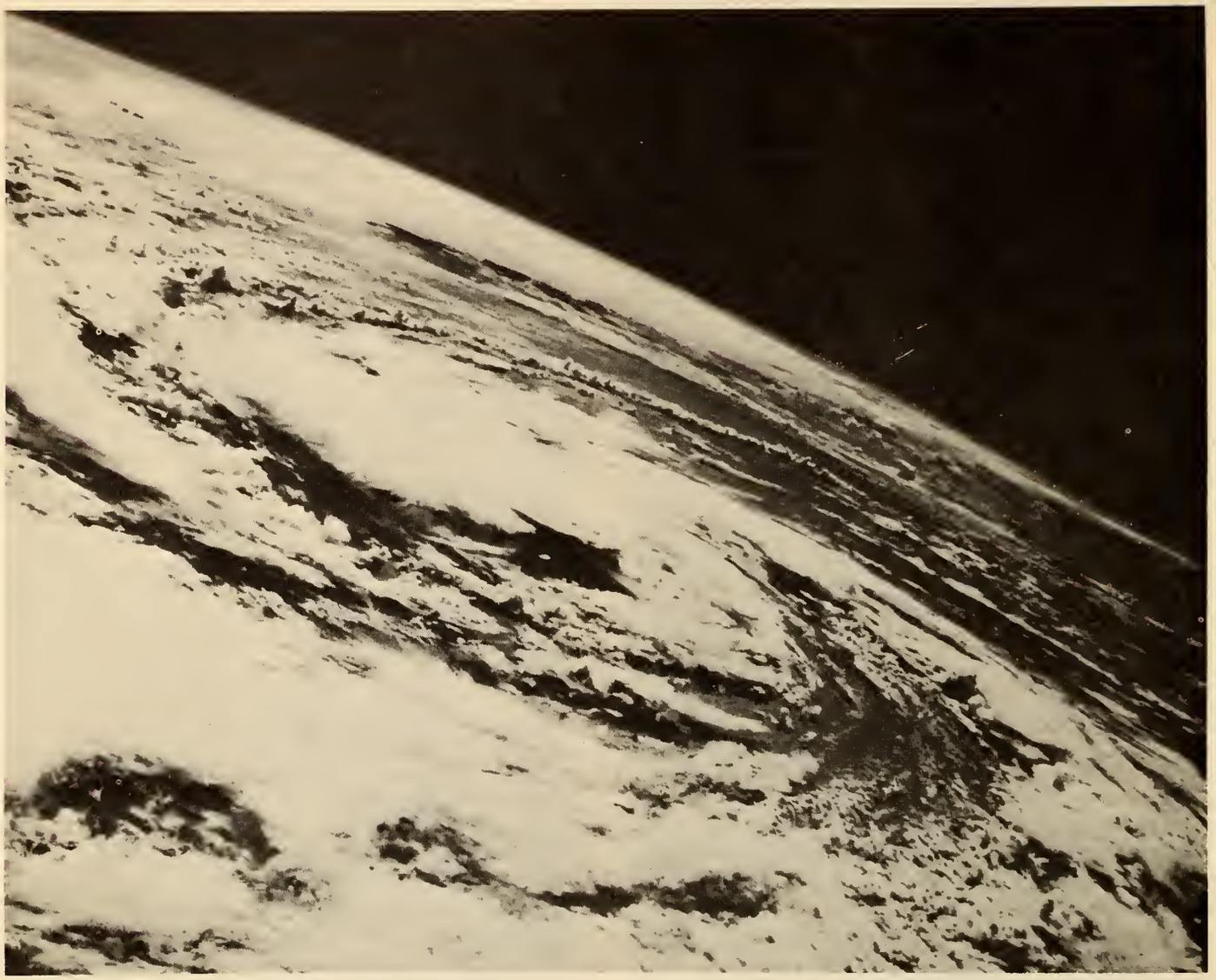
A new objective prediction technique was developed and given experimental use during the 1969 hurricane season. This method employs mean layer winds and geopotentials for a deep layer of the troposphere, the depth being proportional to the central pressure of the hurricane whose movement is to be predicted. A simplified primitive equation (PE) model developed by the NHRL has been used to predict the changes in the smoothed flow for a 48-hour period; a point vortex representing the hurricane was translated in this changing flow. The NHRL, with assistance from the NHC's hurricane specialists, has been using 1968 hurricane Gladys data for dependent case studies using this technique.

During the reporting period, the NHC initiated research on the reassessment of the hurricane prediction problem which consists of three basic and interdependent facets: development, movement, and storm surge. Investigations were made into the usefulness of hurricane movement predictions whose accuracy depends mainly upon how precise the direction of movement can be computed; the direction of movement depends upon the interaction of circulation in high and low latitudes. This research project focused upon the difficulty in separating the transistory from conservative features for circulation at low latitudes. Unless these transitories are filtered out, the interaction factor will be poorly predicted. Therefore, emphasis is applied toward various prediction techniques. The storm surge for an ideal coastline can now be modeled effectively, but research has shown that the variations caused by local topography can be of such magnitude that the problem must be attacked as a special case for each population center; the physical-dynamical model employed was flexibly designed to accept a variety of topography.

The NHC also developed an operational technique that utilizes a digital computer to define the climatological track of an existing tropical cyclone. All Atlantic tropical cyclone tracks since 1866 were examined. Positions of storms that exhibited characteristics similar to the existing storm (adjusted to its initial position) were computed at 4, 12, 24, 36, 48, and 72 hours after the initial time. The technique makes it possible to compute the probable position of the storm center relative to a given location at a specific time.

In an analogous project conducted by the National Meteorological Center (NMC), experimental hurricane track forecasts to 72 hours have been computed for existing hurricanes by using as initial data the NMC's tropical belt wind analyses, followed by the PE barotropic forecast model calculation for the hurricane seasons of 1967, 1968, and 1969. These experimental hurricane track forecasts were telephoned to the NHC in Miami during FY 69.

During the 1967 and 1968 hurricane seasons, this aforementioned procedure constituted the track forecast. Verifications of these forecasts showed the forecast track to be



Hurricane vortex photographed from a satellite.

south of the actual track in nearly all instances. During the 1969 hurricane season, vortex effects have been added to the earlier procedure. A version of this vortex effect procedure was successfully tested during the 1968 hurricane season.

The NHC conducted an investigation into storm surge utilizing climatological data. Sufficient climatological data were available from 18 great hurricanes (950 millibars or less) to show variations and extremes in the water levels resulting from storm surge, enabling a mean profile to be constructed from these data. While the profile has initially been used as a first estimate of the lateral extent of dangerously high hurricane tides preceding devastating hurricanes in low latitudes, NHC scientists are also working on an additional contribution to this concept by adjusting existing theoretical models before storm surge forecasts are made by the computer for each hurricane approaching land.

Satellites are now used routinely to observe hurricanes and tropical cyclones. One such project involved the summarization of the characteristic features of lower tropospheric fields of motion, low-latitude synoptic scale, and weak members of the tropical cyclone family as determined from weather satellites, rawinsonde, and flight data. Qualitative intensity estimates based on available data and known constraints were also made. These intensity estimates and constraints lead to estimates of growth, decay, fluctuation, and transformation and facilitate the application of needed flexible classification schemes.

In another application of satellites to hurricane and tropical cyclone observations, Nimbus 2 High Resolution Infrared Radiometer (HRIR) measurements in the 3.4- to 4.2-micron region and ESSA 1 and 3 pictures were analyzed during the last 2 years to map the growth from West Africa of the 1966 hurricane Inez. The development of Inez passed through two intensity peaks in the tropical Atlantic and Gulf of Mexico before dissipation 28 days after its inception. A new map projection form was used to analyze statistically the cloud field associated with the various stages

of hurricane development. This map projection centers the analysis over the storm and retains some scale regardless of the storm's position. Tropical sea-surface temperature charts in the vicinity of Inez were also derived from Nimbus 2 HRIR data for 10-day periods during September and October 1966.

The availability of satellite pictures has made it possible to document the history of weak tropical disturbances over the North Atlantic Ocean. Such documentation was made through analyzed results from the most recent hurricane seasons—1967 through 1969. More than one-half of the disturbances originated in Africa. Moreover, a number of these African disturbances were followed across the Caribbean and into the eastern Pacific Ocean where they occasionally triggered tropical storms.

The research done by Ballenzweig in the 1950's was updated by NHC using a slightly different approach which computes the departures from 10-day normals for the day that hurricane intensity was reached and for the preceding 2 days. Mean 700-millibar maps for these 2 days are examined to assess the vulnerability of landmasses being related to the actual landfall of hurricanes.

Additionally, the NHC, in cooperation with the NHRL, performed an analysis of forecast errors for the past two hurricane seasons. This includes the construction of probability ellipses for the official forecasts based upon case errors. The new verification program is based upon a digital hurricane advisory that may be introduced operationally in the near future.

With the establishment of a Hurricane Services Branch at the NHC in 1968, four hurricane specialists have been assigned full-time duty in this Branch. The specialists have been improving diagnostic tools and automating procedures. Attention has been given to the development of new and more comprehensive climatological tools for prediction and the development of objective procedures for storm surge predictions. Programs have been completed for automated processing of upper air information in tropical and equatorial areas, for computation of mean tropospheric layer winds and mean geopotentials, and for plot-out of data on map bases. A number of other programs have been developed to prepare daily computations and printouts of deviations from normal, 24-hour changes in meteorological elements, and other diagnostic information.

Hurricane Modification Experiments

The program for hurricane modification experiments, Project Stormfury, is conducted in cooperation with the Navy and with support from the Air Force. Experimental flights have been made into hurricanes to investigate the feasibility of seeding supercooled clouds with silver iodide, under the hypothesis that the release of the latent heat of fusion in certain sectors of the storm's structure will produce changes in the pressure gradients or in areas of divergence that will either change the intensity of the hurricane or its direction of travel. During FY 69, NHRL initiated a study of hurricane modification by reducing the rate of heat and energy transfer from the sea to the atmosphere inside the storm's circulation.

Theoretical Investigations and Models

Encouraging results have been obtained from NHRL's multilevel PE model of tropical cyclones; numerous integrations have been carried out with results that resemble the life cycle of real tropical cyclones. Results obtained so far have encouraged attempts at simulating some of the field experiments planned by Project Stormfury.

Extensive studies of a two-level balance hurricane model were in progress during FY 69 to determine boundary layer effects on tropical cyclone development. A PE version of this model has also been devised and programmed for direct studies of the effect of the gradient wind assumption on results obtained from hurricane models.

Hurricane Structure and Energetics

The NHRL has conducted a series of research programs to give a more complete understanding of hurricane structure and energetics for designing modification experiments and improving forecasting techniques. An intensive study of the 1964 hurricane Hilda from the formative through the decay stages did much to establish these earlier tentative findings. Warming aloft precedes deepening to hurricane intensity; characteristic cloud forms occur during and after intensification; earlier energy budgets for momentum, heat and moisture transfers, and kinetic energy were confirmed by research aircraft data; and the greater part of latent heat transfer occurred at relatively large radii, but the transfer was more intense closer to the ring of maximum winds.

The same research approach was applied in a shorter study of the 1966 hurricane Inez—a very small, very intense, typical Atlantic hurricane. Data collected by flights near and above the top of the 1966 hurricane Faith were analyzed to fill gaps in knowledge of temperature, wind, and pressure distributions near the tropopause over severe hurricanes. Results obtained were used in evaluating hurricane simulation experiments.

Diagnostic Studies of Other Tropical Systems

The study of hurricanes was supplemented by research on other tropical disturbances that can thrive under the same conditions. A seven-level diagnostic model has been developed that includes frictional convergence of moisture in the low levels, idealized and parameterized release of heat in the vertical, stream function and geopotential heights related through the balance equation, and a tabulation of contributions by the various terms in vorticity and thermodynamic equations.

Other studies made include: An evaluation of aircraft data gathered on a synoptic experiment in the tropics (Project ECCRO—Eastern Caribbean Cooperative Reconnaissance Operations) in studying the structure of a steady-state cold low (in the tropics) relating circulation to moisture, cloud, and precipitation patterns; and a study of the evolution of the wind and temperature fields of two tropical disturbances crossing the Caribbean, one of which remained a steady-state easterly wave and the other deepening into the 1962 hurricane Alma.

Forecasting Hurricane Motion

A multilevel PE model for hurricane forecasting has been developed and programmed at NHRL. The model has been tested on nonhurricane data for a relatively small geographical area. In the case of hurricane Alma, the model successfully forecast the development of a vortex. The movement of the developing cyclone was also successfully predicted.

Continued tests of the PE model on Alma and the 1965 hurricane Betsy data were also conducted in FY 69. Equation derived as part of the prediction model were used to analyze vertical motion patterns and energy transformations associated with several tropical weather systems, including easterly waves, tropical cyclones, and an upper tropospheric cold low.

Research Flight Facility

In support of both research in hurricanes and severe local storms, ESSA's RL maintains the Research Flight Facility (RFF) headquartered at Miami. The RFF uses aircraft specifically instrumented for meteorological research to penetrate hurricanes and to obtain meteorological data in the vicinity of squall lines (tornado-spawning clouds) and other severe local storms. These aircraft gather meteorological data at various atmospheric levels up to their maximum operating ceiling of about 20,000 feet. One of RFF's aircraft has a greater maximum operating ceiling, permitting its use to obtain meteorological data at elevations between 30,000 and 43,000 feet. Other RFF aircraft are used for testing meteorological instrumentation and for making meteorological measurements on appropriate storms. During those seasons of the year when hurricanes and severe local storms are not prevalent, RFF aircraft are employed in projects which provide data needed for weather modification, snow storms, and other investigations.

Tornado and Severe Local Storms Forecasting

Work continued during the reporting period in the Techniques Development Laboratory (TDL) of WB on the development of computer-oriented techniques used by the NMC to predict the areal location of severe weather outbreaks and the measure of expected intensities and to verify severe weather forecasts. During the latter part of FY 68, three programs—trajectory, tornado indices, and verification—were run daily. Verification of 24-hour temperature forecasts produced by the trajectory program during June 1968 indicated considerable improvement.

A major achievement by the TDL in FY 69 was the development and successful testing of an operational three-dimensional trajectory model which produces skillful 24-hour forecasts of temperature, dew point, relative humidity, and net vertical displacement at the surface, 850 millibars, and 700 millibars. These computer forecasts are transmitted twice daily from NMC to the Weather Bureau Forecast Offices (WBFO) by means of facsimile. Use of this new information by forecasters at NSSFC is expected to improve significantly the accuracy of tornado and severe storm forecasts.

The TDL and NSSL worked together to develop an analysis-forecast system for the NSSFC, a comprehensive system which included: (1) automatic data processing; (2) objective and diagnostic analysis; (3) prediction capability; (4) output and display of information; and (5) verification. Both dynamical and statistical models were used. During FY 68, a system was designed to provide hydrostatic checking of upper air data. A computer program which provides an objective analysis of the low-level moisture field was put into operation at NSSFC in April 1968. In FY 69, a modified version of the Bushby-Timpson 10-level fine-mesh PE model was developed and utilized to study the dynamics of the atmosphere in severe storm situations.

Severe Storm Morphology and Dynamics

The NSSL has begun research efforts aimed at the development of a comprehensive description and explanation of severe storm characteristics. Investigations during the last 2 years indicated that the contribution of a previously neglected source of rotation for thunderstorms may be significant. The evidence suggests that large thunderstorms have a tendency to rotate, to be severe, and to move along trajectories not wholly explained by their rotational characteristics.

Instrumentation and sampling techniques involving aircraft and balloons were developed to obtain data on updraft location, speed and configuration, size of inflow areas, inflow flux values, and parcel trajectories in relation to individual thunderstorms. These sampling techniques yielded additional information on the internal structure of storms and their energy budgets.

Dramatic variations in the vertical distribution of wind and temperature near a severe thunderstorm were analyzed in detail, based on data from an instrumented 1,500-foot television tower and associated observations. These data indicated that vertical extrapolations of surface measurements may be invalid in regions which are influenced by cold air outflow from thunderstorms.

Storm Hazards to Aircraft Safety

A cooperative investigation involving the NSSL, the Air Force's Air Weather Service, and the Canadian National Research Council during the spring of 1968 produced flight data on turbulence and temperature gradients in the vicinity of major thunderstorms. Flights by B-57 aircraft provided photographic data on the distribution and growth of convective cloud tops above 40,000 feet. Turbulence and temperature-sensing equipment, provided by a British concern, were carried aboard aircraft flown over the tops of large cumulonimbus clouds. Flights were made by a Canadian National Research Council T-33 aircraft to measure turbulence at altitudes below 15,000 feet in the vicinity of thunderstorms. Flights were also made between thunderstorms in areas where aircraft operators might be inclined to penetrate a line of thunderstorms; these flights provided information on aircraft hazards in the vicinity of severe local storms. Based on the evidence derived from this cooperative aircraft observation program in Oklahoma, the NSSL staff

was able to collaborate with the FAA in developing that agency's *Advisory Circular 00–24, Thunderstorms*—a guide for airmen on minimizing the risks of hazardous flying conditions.

Electricity of Severe Storms

Because electricity associated with other features of severe storms is poorly understood, attempts were made in NSSL to measure areas of lightning activity and to relate them to areas of precipitation, locations of air, inflow and outflow, and the direction and speed of storm movement and development. Positioning measurements of intracloud lightning associated with a major tornadic storm in central Oklahoma were studied. Observations of lightning radiation were made with improved sferic recording equipment. Data obtained in these experiments appear to be significant and should lead to an understanding of the role of electrical energy in severe storm processes and their manifestations of precipitation and high winds.

As a result of investigations by the staff of RL's Ionospheric Telecommunications Laboratory (ITL), indications are that the radiation pulse train produced by intracloud lightning contains information about the effective height of the discharge and its position. This possibility was studied by NSSL in FY 69, and the sferic measurements of a tornadic storm were reexamined to derive three-dimensional distributions of the sampled lightning.

Doppler Radar Techniques

Reports on a unique 1966 experiment conducted by NSSL involving two Doppler radars were completed during the reporting period. These studies revealed many of the practical problems involved in the determination of the true vector wind velocity with a system of Doppler radars, each measuring the spatial distribution of radial wind components. From these studies, the design of an improved Doppler radar and associated systems for processing Doppler data was possible.

Weather Radar Interpretation

Research into weather radar interpretation by NSSL involves two objectives: (1) Determination of the relationship between weather radar data and associated meteorological phenomena—rainfall rate, hail, and tornado occurrences; and (2) development of effective means for analyzing and displaying the fields of radar data and the inferred associated parameters. Continuing staff collaboration between NSSL and the Fort Worth, Tex., River Forecast Center resulted in improved knowledge of the relationship between radar data and rainfall rate, and in advanced concepts for effective processing of radar data for river forecasting. Substantial advances were made in defining the relationship between radar echo intensity of thunderstorms and associated rainfall which may lead to use of radar data in the national weather observing and reporting systems, application of radar data in severe storm detection, and identification and investigation of severe storm morphology and dynamics. In FY 69, NSSL used digital radar data collected at 15-minute intervals to examine the short-term stability of severe storm patterns. These data, unique in quantitative accuracy and comprehensiveness, offer promise for determining the association between storm events and other meteorological parameters.

The Equipment Development Laboratory (EDL) of the WB in FY 68 conducted research on digitizing radar returns over a given grid, the digital value being indicative of one of six Z-levels of the intensity. This approach involved the interface of a video integrator digitizer with the output of the WSR–57 radar which formatted the radar return for near real-time transmission to a computer site. In FY 69, a systems engineering study on uses of digital radar data and on ways to digitize radar data was completed.

Thunderstorm Forecast Technique Development

Thunderstorm forecast technique development was formally initiated during FY 67 as a collaborative research effort between the staffs of the NSSFC and NSSL, and was directed toward improving operational techniques for analysis of the current state of the atmosphere and more efficient use of observational data. Significant progress was made during FY 68 in objective and automated analysis and data processing techniques. Objective analyses that resulted from this joint research effort included the low-level moisture field and calculations of the kinematic vertical velocity. Automated procedures for checking radiosonde data for hydrostatic consistency and coding errors were introduced and have resulted in significant increases in daily soundings usable at NSSFC on a real-time basis for severe storm forecasting and warning services. Research in FY 69 concentrated on the development of a fine-mesh numerical model applicable to the study of the dynamics of small-scale weather systems.

Data Acquisition and Processing

A major objective of NSSL's R&D program in severe local storms is to acquire comprehensive and accurate data on the meteorological parameters associated with severe storms and to process these data into a useable form that meets the data requirements of NSSL. A digital recorder for the wind and temperature systems was installed on a 1,500-foot television tower. High-quality measurements of temperature and horizontal wind are now obtainable at 1-second intervals at the surface and at six levels up to 1,458 feet above the ground.

In a joint program with the Army and the Air Force, observations were obtained from 10 closely spaced rawinsonde stations during the spring of 1968. Simultaneous ascents were made at 60-minute intervals from all stations during important weather situations. The network of surface weather stations was augmented with an internal cross of 12 new stations spaced 5 miles apart. Sixty-one stations recorded continuously during the experiment, measuring such quantities as rainfall, temperature, relative humidity, wind direction and speed, and pressure.

With the closer spacing and special arrangement of sta-

tions, NSSL continued systematic measurements of pressure, temperature, and wind fields associated with such local severe storm features as tornadoes, shafts of hail, wind, and intense rainfall in FY 69. The analysis of the increased density of surface measurements in the vicinity of severe storms aided in the evaluation of severe storm models. A program to use tower wind measurements for computing the magnitude of the vertical shear of the horizontal wind between successive tower levels was underway during the reporting period.

AGRICULTURAL WEATHER SERVICES

Service Programs

The Agricultural Weather Services (AWS) of ESSA's WB are designed to provide specialized weather observations, forecasts, warnings, and reports to the agribusiness community as a supplement to the Basic Weather Services. The Department of Commerce (DOC), through ESSA, is responsible for planning and conducting the AWS. The Department of Agriculture (DOA) also assists in planning for the AWS and participates in cooperative programs for observation, communication, and distribution of information to users.

The AWS's operational program involves specific weather forecast formats and techniques that are tailored to meet the needs of farmers, are devised by WB agricultural meteorologists, and are disseminated daily through rapid communications outlets. Technical studies in meteorology, directed toward meeting the weather forecast needs of agriculture, are conducted by agricultural meteorologists in cooperation with agricultural scientists at major Agricultural Experiment Stations throughout the country.

Weather plays an important role in almost all phases of agricultural production. Agriculture decisions related to or influenced by weather include: (1) time of planting, method, and depth; (2) type of time and frequency of pesticide application; (3) soil cultural practices; (4) harvest schedules for equipment and crews; and (5) livestock production.

Individual weather-influenced decisions in agriculture fall into two broad categories. The first type consists of those weather factors against which protection can be provided or positive action can be taken; for example, protection against frost, drought, or strong wind. Continuous protection is possible against certain weather phenomena although it may be expensive or impractical. The optimum decision may range from no protection to continuous protection, depending upon the value of the enterprise, the cost of protection, and the climatic probability of occurrence of the weather phenomenon in question.

The second type of weather-influenced decisions consists of those weather factors in which continuous protection cannot be provided or continuous positive action cannot be taken; for example, the protective or positive action to be taken against rain at haying time would be to delay the cut, but such a delay cannot be continued indefinitely without decreasing the quality of the hay or without interfering with other crop schedules.

Adequate weather observations, forecasts, and advisories can play an important role in many types of costly farm management decisions.

Technical Studies Programs

The effectiveness of the AWS is highly dependent upon a successful combination of knowledge from the fields of meteorology and agriculture. The need exists to apply the results from R&D in meteorology and agriculture to the AWS, and particularly to develop agrometeorology to meet the farmers' planning and operational problems.

The degree to which weather information may be successfully applied to the solution of agricultural problems depends on several interrelated factors which include: (1) the detailed extent of crop or livestock response to one or more weather factors; (2) the climatic probability of occurrence of several influential weather elements; (3) the ability of the meteorologist to establish the probability of occurrence of a particular weather phenomenon of significance in agricultural operation; and (4) the ability of the agriculturist to make and act upon alternative decisions, based upon timely weather information, which result in economic gain (or avoidance of loss).

In meeting the requirements and objectives of the AWS, the cooperation of Agricultural Experiment Stations, Agricultural Extension Services, and Colleges of Agriculture is invaluable. The agricultural meteorologists, located at Agricultural Experiment Stations, have among their responsibilities that of cooperating with Agricultural Experiment Station scientists in technical studies relevant to agriculture-weather relationships, and that of applying these relationships to the AWS and to farming practices.

Cotton lint moisture meter used to devise an objective method for forecasting early morning moisture content of cotton lint.

Tower, sensing equipment, and recorders for measuring temperature and humidity to provide data for frost forecasts.

Solar radiation, moisture, and temperature are key meteorological elements in the growth and development of plants and animals. Plant growth and development are determined by the amount of insolation (solar radiation) that can be converted by the photosynthesis process into plant tissue. Farm animal production is controlled by the amount of available feed—forage, silage, and hay—and by the ambient environmental conditions in which the animals are grown.

Soil moisture and temperature have an effect on the rate of seed germination and the vigor of young plants. Moisture in the soil, in the air. and on the leaves and stems of plants influences the rate of growth of crops; the incidence and persistence of virus, fungus, and bacterial diseases on these crops are related to moisture.

A major concern for agricultural scientists, extension personnel, and agricultural meteorologists is to establish the qualitative and, if possible, the quantitative relationships between weather and various phases of agricultural production. These relationships help establish requirements for meteorological information in various types of farm activities and alert meteorologists to agriculture's changing needs for weather information throughout growth, development, and maturation stages of plant and animal production.

The increasing demand for water in agriculture to meet irrigation needs is an important economic factor for dryland farming. Technical studies involving the measurement of soil moisture and prediction of water use over periods from 1 day up to 2 weeks are an important part of the AWS program in dryland agricultural areas.

The quality of cotton has a high correlation with the moisture content of lint at time of harvest. Studies on the measurement and forecast of moisture at picking time are important to the cotton harvest.

Many plant diseases are highly affected by moisture on the leaf surface. Technical programs to improve leaf wetness measurements and forecasts of dew duration are important functions of the AWS. Technical studies on the influence of weather on plant diseases are conducted by plant pathologists and agricultural meteorologists through continuous spore sampling in field plots, continuous dew recordings for the area, and collection of disease data during the growing period.

Fruit production, from blossom to harvest, is highly susceptible to low temperature. The ability of the farmer or orchardist to protect his fruit crop against damaging low temperatures depends to a large degree upon the thickness of the critically cold air layer above the ground. Agricultural meteorologists gather data for forecasts of minimum nighttime temperatures and estimates of heat requirements to prevent frost damage.

AIR POLLUTION SERVICE

Service Programs

The air pollution programs of ESSA support Federal, State, and local pollution abatement and control activities. These programs include specialized meteorological forecasts (such as the daily Air Pollution Potential Advisories), climatological studies, and consultative services. The Air Quality Act of 1967 gives the Department of Health, Education, and Welfare (DHEW) responsibility for designating Air Quality Control Regions within the country, for establishing air quality and pollutant emission standards in those Regions, and for controlling air pollution in noncontinuous Regions of the country.

Meteorological support is needed for these Regions because atmospheric processes materially affect the transport and dilution of pollutants. The DHEW, the lead agency for air pollution control in the United States, has designated ESSA to provide meteorological research and operational weather support to the Air Quality Control Regions.

Research and Development Programs

Air pollution R&D programs in ESSA for the Air Pollution Service are conducted both by the WB and RL's Air Resources Laboratories (ARL). As an essential part of this Service, large-scale Air Pollution Potential Advisories are prepared by the WB's National Meteorological Center (NMC). These Advisories provide advance notice of potentially hazardous air pollution conditions for use as large-scale guidance by field forecasters who prepare specialized forecast products on the atmospheric potential for dilution and dispersion of pollutants over discrete portions of the conterminous States. The forecast products are based partially on computer-produced predictions of the height of the atmospheric mixing layer and wind speed within this layer where pollutants are normally entrapped.

The ARL perform R&D on meteorological diffusion, transport, and deposition of atmospheric contaminants to attain a greater understanding of processes controlling atmospheric pollution and to find prediction and abatement procedures. Special meteorological activities are performed for the Atomic Energy Commission (AEC) and for DHEW's National Air Pollution Control Administration (NAPCA). Operational and consultative meteorological services as required are provided by ARL to all activities of the NAPCA.

Meteorology of Air Pollution

Although funds within the WB are not specifically earmarked for air pollution meteorology R&D, the need for improved air pollution forecasts has resulted in the establishment of ad hoc applied research programs at both the NMC and various Weather Bureau Forecast Offices (WBFO). The WB research activities are concerned with predicting the atmospheric potential for air pollution and with determining the efficiency and effectiveness by which the atmosphere dilutes and disperses emitted pollutants. The level of air pollution potential varies directly with the thermal stability and inversely with the transport wind and mechanically and convectively produced wind turbulences. Problems in air pollution meteorology concern the choice of variables for describing these relationships and the ability to predict their future values.

Research in air pollution meteorology by ARL includes studies on transport and diffusion, urban diffusion modeling, air pollution potential forecasting, dilution climatology, mesostructure within the urban boundary layer, and effects of urban air pollution on weather and climate. Current methods employed by the WB to predict air pollution potential are based partially on early R&D work by ARL.

The Development Division of the NMC is working upon a "stagnation index" model based on several byproducts of the primitive equation (PE) numerical prediction model. The emphasis is to determine those critical values—relative humidity, lifted index, vorticity and vorticity change, 850-millibar temperature change, and boundary layer winds—considered as functions of known air quality variations which are available from the operational numerical model to use as input to a macroscale atmospheric stagnation index. Concurrently, research is being done to improve forecasts of mixing height and of transport wind within the mixing height.

The WB established Environmental Meteorological Support Units (EMSU) in several major cities during the closing months of the reporting period. These Units observe and predict occurrences of high air pollution potential over urban areas. The major R&D effort by the EMSUs integrates the mesoscale effects on climate produced by the physical attributes of the cities with the synoptic scale air pollution potential. Each city has a unique heat budget, pollution, and topography which contributes to the generation of a local climatic regime. The problem is to determine how the mesoclimate of each city can be used to predict local weather variations and to particularize the pollution potential forecasts for the urbanized area.

Using urban low-level soundings and available air quality data, the EMSU meteorologists are trying to establish a statistical relationship between meteorological variables and pollutant concentrations. The assumption made is that good linear relationships are probable between pollutant concentrations and local wind vector, stability, and inversion height and intensity. The development of local statistical models is underway so that mesoscale predictions can be improved.

During the last 2 years, a comprehensive investigation of the transport and dispersion of plumes from 800-foot stacks at a coal-burning power station complex in western Pennsylvania was initiated by ARL under contract to NAPCA. Measurements of plume rise, plume geometry, and dispersion by instrumented helicopter and mobile Lidar (light detecting and ranging) were made. An analysis of data from low-level tracer tests, conducted in the St. Louis, Mo., metropolitan area, revealed numerical urban effects which enhance plume dispersion.

Tabulations of mixing depths and vertically averaged wind speeds for 41 WB upper air stations are being analyzed to yield an air pollution potential climatology for the conterminous States. Research continued on the development and validation of urban diffusion models and quantitative air pollution potential forecasts. The relationship between atmospheric turbidity and aerosol pollutants remains under study, and research is being pursued on the role of ambient temperature and ultraviolet radiation in the creation and decay of photochemical air pollutants.

Studies on the thermal and motion fields in the planetary boundary layer are directed toward the simulation and development of techniques for forecasting boundary layer parameters used in models of urban dispersion processes, and toward the development and validation of a "mass-balance" model of photochemical air pollutants. Results from several pilot field studies in the Cincinnati, Ohio, metropolitan area indicated that unexpected modification of the thermal structure of the surface boundary layer occurs over the urban area during nocturnal inversion conditions.

Comprehensive national surveys of climatological air pollution potential and atmospheric turbidity were completed during the reporting period. Annual and seasonal ground-level concentration distributions for selected air pollutants

were provided as meteorological input to Air Quality Control Regions.

Mesoscale Transport and Diffusion

The aerodynamic effect of a large urban building complex upon atmospheric diffusion rates was determined quantitatively by tracer experiments; these experiments measured the downwind concentrations in actual flow and also estimated such concentrations from undisturbed flow turbulence characteristics. Research revealed that increased dilution rates by a factor of about three were present at distances 600 meters downwind.

Another field experiment was initiated to study the aerodynamic effect of a single rectangular or cylindrical building upon atmospheric diffusion rates. This experiment involved an investigation of the relationship between surface boundary layer turbulence characteristics and surface deposition of submicron particulates.

In a continuing study of internal boundary layer structure above marsh grass surfaces, measurements of vertical velocity were made to study turbulence characteristics. Spectral density estimates of the vertical wind component in the region of 3.5 Hertz were used to estimate the rate of kinetic energy dissipation. Values were found to decrease with height and to increase with wind speed.

Relative diffusion at a height of 3 kilometers was studied by means of simultaneous tetroon (balloon) releases at the Nevada Test Site. In another experiment, 42 tetroons were tracked by radar past the 1,500-foot Bren Tower to obtain additional information for analyses of the ratio of Eulerian and Lagrangian wind scales.

Global Diffusion and Stratosphere Radioactivity

A study of the differences in behavior between particulate strontium-90 and gaseous carbon-14 in the stratosphere was completed. Results indicate that for time periods of 1 year or more, particulate fission products can be used as atmospheric tracers below 30 kilometers; above this level, the fall rates of particles may become significant. These data, together with other radioactive tracer data, have been used in developing a kinematic model of stratospheric motions.

The design and procurement of operational carbon-14 samplers were completed. A successful test flight at 21 kilometers of the newly developed balloon-borne molecular sieve carbon-14 sampler was conducted in February 1969. A test at 36 kilometers in May was also successful, but results from this test revealed that a modification of the filter beds may be necessary to achieve maximum collection efficiency at high altitudes.

A technique has been developed for estimating rapidly the future worldwide deposition of long-lived radioactive debris injected anywhere into the atmosphere. Adapted to a computer, this technique will estimate the consequences of possible future atmospheric nuclear testing. Problems associated with short-lived radioactivities were also investigated.

An airborne investigation of the radioactive argon-41 plume from the Brookhaven reactor in New York, using aircraft equipped with large silver-iodide crystal detectors and an onboard computer, has yielded data on plume behavior 300 miles from the source.

The role of the high-reaching thunderstorm activity in bringing iodine-131 to the surface has again been verified by studies in the Midwest; a more complete study of all instances of detectable iodine-131 in milk since the end of large-scale nuclear testing in the atmosphere was also made.

Sonic Boom

Investigations into sonic booms at Edwards Air Force Base, Calif., indicated that *N*-wave overpressures correlated well with the Friedman overpressure prediction.

Field surveys are being made to determine the optimum location for a microphone array at Pendleton, Oreg., and to delineate the superboom caused by aircraft acceleration; the Friedman computer program is being used to predict the location of the superboom for various flight configurations and to estimate the overpressures resulting from aircraft accelerations. Attempts will be made to obtain observational verification of the superboom. Arrays are in place to collect meteorological data for comparison with the SR-71 sonic booms. During FY 70, an analysis of the Pendleton data will be made.

Meteorology for Nuclear Testing

To assist programs for testing nuclear weapons, rocket engines, and industrial nuclear explosives, applied research is oriented toward improvements in the meteorological services provided. Models of mesoscale meteorological circulations in geographic areas used for nuclear tests are developed and used with adapted diffusion and deposition models to provide evaluations of radiological hazards. Five radiological hazard models, based on diffusion computation methods, were compared for use in nuclear rocket engine tests during the last 2 years.

Long-range diffusion parameters were derived from data on the dispersion of tetroon clusters and from particulate tracer experiments. Effects of large directional wind shears on effluent deposition were evaluated and corrections included in fallout models. Statistical precipitation forecasting models and a climatology for the Nevada Test Site were completed.

Progress toward a computer-oriented mesoscale meteorological system continued with acceptance of a commercial design for a portable wind-finding radar with a built-in computer interface. Another system contribution was meteorological instrumentation for a 1,500-foot tower and for a long-range airplane.

Research into deposition in flows over mountain barriers and on long-range diffusion continued. Additional progress is expected in adapting computer methods for analyzing streamlines in mountainous wind forecasting. Current diffusion and deposition models used to evaluate potential hazards from underground nuclear detonations were reviewed. New techniques for trajectory prediction are expected to evolve from studies of long tetroon trajectories.

Interoceanic Canal Meteorology

Meteorological data—including wind profiles, trajectories, and surface and radar precipitation measurements—are required to analyze potential fallout hazards that could affect the feasibility of constructing a sea level canal by nuclear excavation in Panama or Colombia. Data collection and analysis were completed, computerized fallout models were developed, and fallout patterns were calculated for the proposed excavation routes.

Atmospheric Turbulence and Diffusion

During the reporting period, the Air Resources Atmospheric Turbulence and Diffusion Laboratory (ARATDL) of ARL made a comprehensive study of the buoyant rise of stack plumes which are urgently required for atmospheric diffusion predictions. Principal findings of the ARATDL study concluded that: (1) Almost all existing plume rise data fit simple models in which buoyancy and momentum are conserved and plume diameter grows linearly with height; (2) under stable conditions, very buoyant plumes follow a "two-thirds power of distance" law of rise for considerable distances; and (3) under neutral and unstable conditions, ultimate heights of plume rise have not yet been observed.

Theoretical studies of the planetary boundary layer have been continued; emphasis is on defining the top of the layer and comparing various planetary boundary layer models.

WEATHER MODIFICATION

Research and Development Programs

The R&D program in weather modification has the potential to benefit the Nation's economy, protect human life, and reduce property losses. Such a program is closely related to other weather activities within ESSA and is guided by goals developed by the National Academy of Sciences' (NAS) Panel on Weather and Climate Modification and by the National Science Foundation's (NSF) special Commission on Weather Modification.

The Atmospheric Physics and Chemistry Laboratory (APCL) of the RL is concentrating its efforts primarily on research which develops the scientific and practical potentialities of weather modification and advances the required technology for application of weather modification through theoretical studies, laboratory investigations, computer modeling of atmospheric processes, and experimental field projects. Present effort emphasizes modification of precipitation, moderation of severe storms (including hurricanes and severe local storms), reduction of hail and lightning damage, and possibility of climate modification either by man's deliberate actions or inadvertently by his normal activities.

Hail and Lightning Suppression

ESSA scientists, through cooperative arrangements with other research organizations in both laboratory and field

Time exposure of multiple lightning strikes in an urban area during a typical thunderstorm.

investigations, are participating in the National Hail Modification Research project to study hail-producing mechanisms. In the summer of 1968, a cooperative research program was begun during the hail season involving ESSA, Colorado State University, and the National Center for Atmospheric Research (NCAR) as participants, and receiving partial budgetary support from the NSF. Aircraft and surface observations were used in evaluating storm characteristics. Studies of the inflow and outflow circulation patterns, speed, and direction below the cloud base, the net divergence and vorticity, and the total water flow within the storm were undertaken. Airborne infrared-measurement techniques, used to determine hailfall patterns and intensities, were evaluated; surface observations were made of hailstone characteristics and hailfall patterns. All aspects of this research have yielded valuable data for development of hail suppression methods.

Studies are underway to develop techniques for altering the electrical characteristics of thunderstorms; this may ultimately lead to methods for suppressing or reducing the severity of lightning. Since 1966, lightning suppression studies have been carried out jointly with the Army. The aim of these studies is to eliminate lightning by using corona current to discharge the thunderstorm electric field before that field reaches values which trigger the lightning discharges. This research has led to detailed measurements of the electric field distribution underneath thunderstorms; from these measurements, a numerical model of charge development and distribution in the storm has been constructed to provide information that is essential for effective chaff seeding.

Modification of Weather and Climate by Air Pollution

Research is underway on the effects of industrialization, urbanization, and agricultural practices upon global and local climates. The role of air pollution is under study to determine its long-term effects on the natural climate of the earth. Specifically, the R&D program in air pollution deals with the radiation energy budget and with inadvertent weather modification caused by the action of gases (carbon dioxide and ozone), particulate matter (cirrus clouds), and surfaces (albedo).

As part of the R&D program, an additional benchmark air sampling station was put into operation during the reporting period with the establishment of a station at the Alpine and Arctic Research Institute facility west of Boulder, Colo. The sampling programs at the Amundsen-Scott Weather Bureau Office (WBO) in Antarctica and at Mauna Loa Observatory in Hawaii were expanded. Research continued on aerosols, radiation, and wind regimes along mountain slopes, electrification of warm raindrops, and development of an ion-gun to generate highly charged air pockets.

One observer from the APCL participated in the 1967 global expedition of the USC&GS ship *Oceanographer*. A wealth of data on aerosols, atmospheric electricity, radiation, carbon dioxide content, and cloud nuclei was obtained. Similar measurements were conducted early in 1969 from the USC&GS ship *Discoverer* which participated in the Atlantic Trade Wind Experiment (ATEX) and from ships involved in the Barbados Oceanographic and Meteorological Experiment (BOMEX).

Great Lakes Snow Modification

In the Great Lakes region, intense snowstorms often paralyze communities along the southern shores of Lakes Erie and Ontario. These storms are the result of flow of cold polar air over the relatively warm Lakes during the late fall and early winter. Exploration into these lake snowstorms has been carried out for several years; research results from a New York State pilot project on snow modification revealed that very heavy seeding of the clouds just offshore could lessen disruptive aspects of storms by redistributing the snowfall downwind over a wider geographic area on the lee side of a major lake.

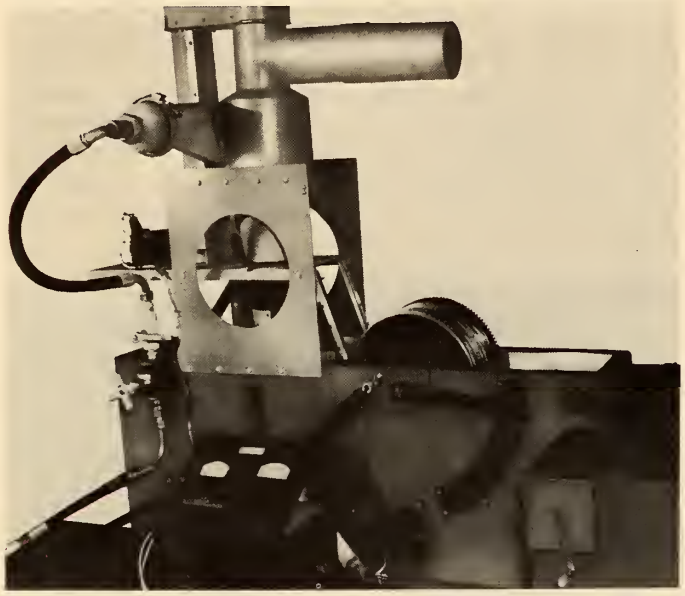
Images of snowflake crystals on the APCL's snowflake replicator.

Other studies were conducted during the last 2 years on the dynamics of snowstorms over the Lakes. From these studies, which yielded a complete set of lake snowstorm characteristics, development of a theoretical model is now possible. The microphysical development of lake snowstorms has been traced in terms of crystal growth, precipitation time, and advection distance of snow crystals. Experimental seeding of supercooled natural clouds to achieve complete glaciation, to minimize riming, and to advect more snowfall farther inland appears feasible.

Modification of Tropical Storms and Cumulus Clouds

Tropical storm modification research increases knowledge of natural, artificially stimulated, or suppressed tropical convective activity and mechanisms involving isolated cumu-

lus clouds, thunderstorms, and tropical disturbances—both maritime and continental. Major research projects in this field include: Development and refinement of numerical computer models to predict more efficiently both the natural growth and decay processes of tropical cumulus clouds and their seedability under selected conditions; improvement and testing of more efficient and effective pyrotechnic cloud seeding chemicals, devices, and dispensing mechanisms from aircraft; development and refinement of a new generation of airborne hydrometer sampling and recording probes and instruments; increased emphasis on the study of mechanisms involving warm clouds and their possible modification through use af a variety of seeding materials; determination—based on data obtained at the surface, by aircraft, and from calibrated land-based radars—of changes in cloud and precipitation rate and amount that occur as a consequence of natural conditions and of seeding with silver iodide and other chemicals; and evaluation of data on both natural and artificially stimulated ice-crystal development and decay in convective activity as observed by airborne ice and liquid water (hydrometer) sampling devices.



Silver iodide generator for cloud seeding. Photo courtesy of U.S. Air Force.

Northeast Rain Augmentation

A theoretical study of cloud seeding potentialities in cyclonic storms in the Northeastern States indicated that to augment the particle concentration will increase the rate of rain if the cloud has excess liquid water stored; moreover, the rain potential is greater in a cloud with a fluctuating updraft than in one with a steady updraft.

Research continued during the reporting period on rain augmentation from extratropical cyclones, using realistic updraft structure models as measured with Doppler radar. The effects of introducing the seeding agent from aloft (aircraft seeding) or below (surface seeding) were investigated.

Instrumentation and Data Handling

A rain gage that continuously monitors the amount of rain encountered in airplane flight was developed and flight tested.

Results of localized seeding in cloud layer. Photo courtesy of U.S. Air Force.

Under development is a design for a panoramic real-time flight path and wind field display, with a centered radarscope display overlay. This new design incorporates a small airborne computer for data handling and includes additional output that provides the divergence and vorticity over a planar closed flight-loop.

Computer programs for graphic presentation of several parameters have been written and tested. Immediately after the completion of the flight, graphic presentations are available for application to various field experiments.

FIRE WEATHER SERVICE

Service Programs

The objectives of the WB's fire weather programs are to protect life, to conserve natural resources, and to aid and stabilize the economy of the timber industry. These programs have been focal points for the Fire Weather Service which provides weather forecasts and advisories to forest and range management, including fire control agencies in the United States.

Annually, approximately 125,000 fires lay waste to 4.5 million acres of forest land in the United States. Tangible losses—damage to soil and wildlife, loss of stored water, and blighted recreation sites—bring the total annual cost to approximately 500 million dollars. In comparison, fire detection and suppression cost only 200 million dollars annually. Through effective weather forecast support, these losses are reduced and the cost of protecting forest and grassland areas is lessened.

Weather conditions directly affect fire ignition, detection, and behavior. Proper weather information enables the fire fighting organization to time effective preventive action and to take immediate control measures. Day-to-day and hour-to-hour fire control operation must be keyed to existing and anticipated weather conditions.

Forecasts

Cooperative Fire Weather Observing Stations, operated by forestry personnel, collect specialized data needed to make forecasts. Certain Weather Bureau Offices (WBO) are designated as WBOs for Fire Weather in the conterminous States and Alaska; these Offices are staffed with specially trained WB personnel who furnish detailed forecasts to local users.

During periods of unusually high fire danger, fire weather meteorologists prepare and issue warnings as required. Additionally, they release special forecasts covering the immediate vicinity of any fire. Meteorologists also consult with fire control coordinators on the probable effects of predicted weather upon fire danger to forests and upon fire control.

Dissemination

The Fire Weather Service is used by Federal agencies—Bureau of Indian Affairs, Bureau of Land Management, Forest Service, and National Park Service—State forestry organizations, county fire-fighting groups, private timberland owners, and associations of private land users. Fire Weather Service forecasts are issued generally once or twice a day, but timing requirements vary with the needs of the local users. Weather information includes temperature, wind, humidity, timber and brush moisture, precipitation, and thunderstorm activity.

ESSA mobile fire-weather station.

Research and Development Programs

The objectives of the R&D program in fire weather consist of: (1) forecast techniques for such critical meteorological elements as temperature, relative humidity, wind speed, and wind direction; (2) forecast techniques for localization of thunderstorm activity; (3) procedures for small-scale analyses of weather elements involving typical air drainage flow in mountainous terrain; and (4) forecast techniques for important synoptic weather conditions such as strong dry winds. These R&D efforts also support the operational aspects of the Fire Weather Service.

A large portion of the R&D program is directed toward improving the operations of the Fire Weather Service through better forecasts for local areas. Preliminary analy-

ses are made of weather conditions associated with fire dangers, based on detailed reports from forest ranger stations throughout the country. Development and testing of the approved fire weather forecasts are based upon these analyses.

Forecasting Techniques

The Techniques Development Laboratory (TDL) of the WB is responsible for the development of objective forecasting techniques for fire weather. These techniques involve predictions of temperature, relative humidity, wind, precipitation, and thunderstorms for selected stations throughout the United States.

The TDL in FY 68 developed an objective system of map typing to stratify data. Statistics were computed for bimonthly grouping of data at the 23-station Fire Weather Network in southern California. Additional research involved planning a program to determine map types for this Network.

In FY 69, multiple regression equations were derived for nine of 13 fire districts in Alaska. These equations used such predictors as mean layer values of mixing ratio and temperature, thickness, temperature-dew point spread at several levels, and wind velocity at the surface and 500 millibars. The predictands are the occurrence or nonoccurrence of thunderstorms and the number of thunderstorms encountered during a 12-hour period. In addition, single-station multiple regression equations were derived for predicting surface dew point at 89 cities in the conterminous States from circulation forecasts made by the primitive equation (PE) model.

AVIATION WEATHER SERVICES

Service Programs

The Federal Aviation Act of 1958 defines ESSA's responsibility to the aviation community as that of supplying adequate aviation weather programs to promote the safety and efficiency of air navigation.

The aviation weather programs of the WB are incorporated into Aviation Weather Services which furnish the specialized weather reports, forecasts, warnings, and advisories required to serve aviation. Specialized weather reporting contributes to the safety of aircraft operations in the National Air Space System by providing information which assists pilots to avoid or minimize the effects of potentially hazardous weather conditions—such as turbulence, icing, strong winds, and fogs. Such reporting also contributes to the efficiency of aviation operations by furnishing information which assists managers, pilots, and controllers to determine and select optimum cruise levels, tracks, fuel, and payload ratios; to alleviate air traffic congestion; to reduce aircraft delays, diversions, and missed approaches; and to improve planning for effective System utilization of aircraft crews and facilities.

Increasingly, Aviation Weather Services become more important as the national economy expands, as vigorous aviation growth continues, and as air space congestion persists. Because weather is an important related factor in many general aviation accidents, it is a matter of vital safety that forecasts and warnings be adequate and timely. By improving Aviation Weather Services, the degree of hazard involvement in aircraft operations could be substantially reduced.

ESSA's plans for improving the Aviation Weather Services are contained in *Planning Guidelines for a Federal Aviation Meteorological Service,* published in August 1968 by the Federal Coordinator for Meteorological Services and Supporting Research. These plans are in response to the requirements stated by the Secretary of Transportation in his letter of April 25, 1968, to the Secretary of Commerce, and follow the recommendations of the National Transportation Safety Board.

Aviation Weather Observations

Weather observations are required by the Aviation Weather Services to provide the necessary weather reports, forecasts, and warnings. The Basic Observation Networks provide the surface, upper air, and radar observations from specialized and cooperative facilities. The specialized aviation observations primarily support airport landing and takeoff operations. Large gaps in aviation observation reporting still exist, particularly in the mountainous Western States; additional observations are required to support safe aircraft operations adequately.

Forecast Preparation

The National Meteorological Center (NMC), the National Hurricane Center (NHC), and the National Severe Storms

Meteorologist preparing forecast of flight weather conditions over the North Atlantic Ocean.

Forecast Center (NSSFC) prepare nationwide forecasts for domestic aviation as their contribution to the Aviation Weather Services. Using these nationwide forecasts, the Weather Bureau Forecast Offices (WBFO) prepare terminal forecasts for airports within their respective zones of responsibility. Twelve- and 24-hour terminal forecasts are prepared every 6 hours; these forecasts are updated continually to keep aviation interests informed of significant and changing weather conditions important to efficient aviation operations and effective flight planning. Twenty-two WBFOs also issue domestic aviation area forecasts and In-Flight Weather Advisories to warn pilots and controllers of potentially hazardous weather.

International aviation forecasts are prepared in accordance with procedures established by the International Civil Aviation Organization (ICAO). The NMC and six WBFOs, in cooperation with the Canadian High-Altitude Forecast Center at Montreal, Quebec, provide forecasts used for international flight documentation and planning. These Offices and Centers also issue forecasts of significant weather that may be potentially hazardous to flight safety over extended international routes.

Dissemination

A cooperative dissemination arrangement exists between the WB and the Federal Aviation Administration (FAA) as part of Aviation Weather Services. Telephone, person-to-person, and mass dissemination briefing methods are employed to disseminate aviation weather information to pilots. Individual pilot briefings for domestic flights are handled by FAA personnel at Flight Service Stations (FSS) and by WB personnel at Weather Bureau Offices (WBO). All pilot briefers, both FAA and WB, have certificates from the WB. A flight service quality control program is maintained by the WB to insure that individual pilot briefings given by either WB and FAA personnel meet standards for flight safety. Forecast texts, prepared and furnished to the FAA by the WBFOs, are given mass dissemination over the Pilots Automatic Telephone Weather Answering Service (PATWAS) and the continuous Transcribed Weather Broadcasts (TWEB). Pilot briefings for international flights are furnished by WBO personnel.

Research and Development Programs

The objective of the R&D program in aviation weather is to provide basic improvements to the operations of the Aviation Weather Services. This broad objective is being attained through continuing efforts in systems analysis, and in the design, development, and testing of new and improved techniques and equipment that are applied specifically to forecasting and clear air turbulence (CAT) occurrences.

Forecasting

In the field of forecasting, major emphases are placed upon development of objective automated short-period terminal weather forecasts, improved en route severe weather forecasts, and new flight equipment and procedures to overcome problems that arise from the introduction of new aircraft.

Specifically, R&D efforts are directed toward: (1) Developing a comprehensive and logical plan for Aviation Weather Services which would allow orderly modification to these Services as requirements dictate and as technology advances permit; and (2) testing and evaluating new equipment and procedures for improved measurements of both terminal and en route weather conditions.

As part of the effort to improve overall aviation forecasting, a Plan for the Aviation Weather Services was initiated by the WB's Systems Development Office (SDO) in FY 69. This plan will identify the essential support characteristics required to provide adequate weather services for flying operations. The Plan will incorporate a review of available data to determine user requirements. Essential information for planning decisions will be derived through application of simulation or analytic modeling techniques to assess cost effectiveness. A cooperative effort was undertaken with the FAA to develop a weather subsystem description for FAA planning use. A large data base pertinent to this Plan, including forecasts of aviation activities through 1980, has been developed.

One of the main thrusts of current terminal forecast research is the development of first-generation computer techniques to automate objective observations of such critical weather parameters as ceiling, visibility, and wind at airports. Through use of computer techniques, these parameters can be continuously updated to provide predictions at these airports.

Development of automated terminal forecasting techniques which could be applied frequently and rapidly to update forecasts at various air terminals was undertaken by the Techniques Development Laboratory (TDL) of the WB during the reporting period. Experiments were conducted to determine the optimum techniques for forecasting ceiling, visibility, and wind at selected terminals up to 12 hours in advance. Automated forecasts of ceiling and visibility, based on simple predictors and the network concept, were produced for eight airport terminals every 6 hours during a 6-month feasibility test period. Results demonstrated that the automated forecasts were feasible but not as accurate as subjective forecasts. Three- and 8-hour ceiling and visibility prediction equations, based on more complex and physically oriented predictors (Boolean combinations), were developed and tested for Seattle, Wash.; similar studies were started for Los Angeles and San Francisco, Calif. Equations based on Boolean predictors alone were not as good as equations based on simple predictors.

In FY 69, the Test and Evaluation Laboratory (T&EL) launched a major effort to develop objective measures of ceiling and visibility. The short-range goal is to develop increased knowledge on the performance and characteristics of current sensor technology; the long-term goal is to automate completely the aviation surface weather observations. In the visibility phase of this study effort, a review of current visibility observation methods and instruments was completed. For cloud measurements, numerous ceilometers were installed and the experimental program to collect quan-

titative data on their performance was initiated. Procurement was started for a light detecting and ranging (Lidar) system which will be used to provide quantitative definitions of cloud boundaries and sky cover.

The T&EL and FAA jointly funded a R&D contract to Stanford Research Institute in FY 69 for development of a mathematical cloud model which would provide a theoretical basis and specifications for an automatic system to describe the state of the sky. The parameters and relations needed to simulate cloud sensor characteristics will be incorporated into the model, and the result will be a digital computer program that can be used to simulate the operation of systems of sensors under a variety of sky conditions.

The Equipment Development Laboratory (EDL) of the WB was involved in research to produce a digital height representation of clouds detected by the rotating-beam ceilometer (RBC). This project involved digital processing of a 120-Hertz signal to determine the presence and time of occurrence of peak cloud envelopes. The resultant device, an RBC Signal Peak Detector, was successfully developed in FY 69. This experimental digital processor, which detects a cloud signal, generates an output pulse after its maximum amplitude has been found, and displays the elevation angle of this peak digitally. The device will be employed by T&EL in its study to automate cloud measurements.

To achieve improved en route forecasts, TDL studied the correlation between tailwind components and temperatures at supersonic transport (SST) flight levels. Correlation data were prepared for 10 possible SST routes. A large volume of statistical data was assembled, but correlations appeared to be small. In another phase, TDL studied the variability of temperatures and winds at SST flight levels. While results indicate that the 12- and 24-hour changes in winds and temperatures tend to increase toward the winter and with increasing heights above 50 millibars, forecasts based on 12- and 24-hour persistence would be adequate for SST cruise operations most of the time.

Clear Air Turbulence (CAT)

Rapid technological developments have emphasized a need for analysis and prediction techniques to determine the location and intensity of CAT. The effort has resulted in: (1) systematic analysis of special pilot reports on occurrence of CAT over North America and surrounding geographic areas; (2) development of preliminary empirical relationships, important for studying the location and intensity of CAT occurrences (intensity results are of value in aircraft design); and (3) a fine-scale analysis of CAT and upper air dynamics and structure to direct future research in locating CAT occurrences.

In FY 69, the TDL performed an analysis of the meteorological conditions associated with CAT over North America and the Atlantic Ocean during four 5-day periods of special data collection. Results showed that a well-developed upper level circulation system is important to the development of CAT and that significant turbulence is almost as frequent over oceans as over land.

TDL also started a study during the last 2 years to compare computerized mountain wave turbulence forecasts for the Denver, Colo., area with manually prepared forecasts and actual turbulence reports from pilots.

A feasibility study was performed by EDL scientists to investigate the use of the existing rawinsonde network as a sensor for CAT. A computer program was developed that provides estimates of CAT probabilities as a function of rawinsonde accelerations. It was found that there is an increased probability of CAT when the rawinsonde accelerations are known to be small.

MARINE WEATHER SERVICES

Service Programs

The Marine Weather Services (MWS) of the WB provide forecasts, warnings, and other advisory information to support such marine activities as transoceanic, coastal, and Great Lakes shipping; commercial fisheries; offshore drilling and mining operations; and recreational boating.

By international agreement involving the Safety of Life at Sea Conventions and the World Meteorological Organization (WMO), certain nations have the responsibility to furnish weather services for specific oceanic areas. The United States has such a responsibility for supplying weather services to users in the western North Atlantic and in the eastern and central North Pacific.

Timely warnings of severe storms and other marine hazards contribute substantially to the safety and efficiency of marine operations. Advisories are broadcast regularly for use on the high seas to guide ships around severe storms and to direct ships to their destinations by selecting the most economical (timesaving) routes. Forecasts and advisories of ice conditions in polar seas and the Great Lakes are essential for marine planning, shipping, and fishing activities. Small boat operations are particularly vulnerable to local changes in wind and sea-state conditions.

Forecasting and Dissemination

Marine forecasts for the oceans are prepared by Weather Bureau Forecast Offices (WBFO) at Washington, D.C., San Francisco, Calif., and Honolulu, Hawaii, based on guidance products distributed by the National Meteorological Center (NMC). The marine weather forecasts of these Offices are broadcast two to four times daily by Coast Guard, Navy, and commercial radiotelegraph and radiotelephone stations. Shipping forecasts for the Great Lakes are furnished by the WBFOs at Chicago, Ill., Detroit, Mich., and Cleveland, Ohio, while forecasting services for coastal waters and inland lakes and waterways are provided by certain specified WBFOs.

Forecasts are distributed also by the ESSA Weather Wire and other means to commercial radio and television stations for broadcast to the public. The WB's very high frequency (VHF) continuous radio facilities include marine warnings, forecasts, and observations for coastal areas.

Research and Development Programs

To provide a proper technological base for increased marine weather activities, a broad R&D program in marine weather has been conducted. Increased national interest and activity in the marine environment and the need to supply information on current and anticipated weather conditions in support of marine environmental operations have led the WB to participate vigorously in a coordinated national effort for expanding the MWS to meet the Nation's growing needs. The WB's responsibility in this field is outlined in policy directives based on the Marine Resources and Engineering Development Act of 1966.

Major benefits from the R&D program in marine weather lie in improved MWS which provide more accurate, timely, and detailed marine forecasts and warnings to the populous coastal regions of the country, to the growing millions of recreational boatowners who use inland lakes and waterways and coastal waters, and to commercial fishing, shipping, and other industries that operate in the marine environment.

Systems Analysis

A major emphasis of the R&D program in marine weather has been the development of a systems approach to provide the basic planning framework for future operations, particularly to identify key technical obstacles to future improvements. Fundamental to improved services is a better description of current marine weather conditions.

Because merchant vessels of all nations routinely ply the oceans, such ships, if properly equipped, are capable of acquiring needed marine weather observational data. The potential for using these "ships of opportunity" as floating meteorological stations within the Automated Merchant Vessel Reporting (AMVER) System was studied during the reporting period by the WB's Systems Development Office (SDO). A computer program was devised and programmed to analyze U.S. and foreign ship traffic patterns to determine those portions of the oceans from which marine weather observations would become readily available if a number of these ships were instrumented. The computer program also prepared analyses of traffic patterns, density, and continuity from the AMVER ship traffic data. The study, concluded in FY 69, showed that from a cost-performance standpoint, it is preferable to use merchant ships rather than Ocean Station Vessels (OSV) as platforms for upper air, surface, and oceanographic observations, at least in the Northern Hemisphere.

Sensors

A major requirement for the MWS are sensors capable of continual operation in the harsh marine environment. The Equipment Development Laboratory (EDL) of the WB conducted a study to obtain data on sensors, telemetry communications systems, and power supplies for use in the design of a meteorological data buoy. This study involved both a literature survey and actual testing of selected air temperature sensors within the marine environment. The sensors were installed on the Steel Pier in Atlantic City, N.J., and data collected until November 1968 when the sensors were destroyed in a storm. Loss of these sensors precluded completion of the planned sensor comparisons.

Launching of an instrumented balloon for upper air soundings above the ocean.

Forecasting Techniques

Although adequate forecasting of the marine environment requires more detailed observations, significant and much needed improvements can be made by proper utilization of existing data. To achieve this end, a forecasting techniques development program was initiated with research

Steps in ESSA's ocean wave forecasting program: (a) weather and sea state observations are made by ships and ocean stations; (b) data are transmitted direct to computers at NMC; (c) computer output is fed into automatic chart drawer; (d) newly drawn chart is run through facsimile machine for transmission to coastal and high-seas forecast centers; (e) marine advisories are sent by teletypewriter to marine radio stations for broadcast; and (f) ships at sea receive forecasts by radio and use them to navigate more safely.

efforts that are concentrated on predicting wave heights and storm surges caused by local and distant storms. Research efforts on wave heights have led to the development of computerized techniques to forecast wind waves, swell, and combined wave heights in the open ocean. Similar techniques are being developed to forecast coastal waves and breakers and waves on the Great Lakes. An objective method was developed—for one location on the east coast—to forecast the surges that are caused by North Atlantic storms. Work is underway to extend this technique to other coastal locations and to include the effects of tropical hurricanes. An experimental technique to forecast wind setup (tilt of the lake caused by strong winds and storms) on Lake Erie is also under development.

The Techniques Development Laboratory (TDL) of the WB conducted research during the last 2 years on improving forecasts of marine surface conditions, such as surface waves on the high seas, coastal waters, and large inland lakes. The major achievement was a wave forecasting program which became operational at the NMC in October 1968. This program produces twice-daily facsimile transmissions of 24- and 36-hour forecasts of wind waves, swell, and combined waves for the Atlantic and Pacific Oceans. These transmissions were the first automated marine surface forecasts issued by the WB. Their accuracy was evaluated at four OSVs in the North Atlantic and found to be generally superior to subjective forecasts prepared from the same data.

This sea-and-swell forecasting program was later modified by TDL to produce teletypewriter forecasts of swell in the island chain of Hawaii and the 1,000-millibar wind velocity in the Bering Sea region of Alaska.

During the reporting period, TDL also compared several methods for forecasting waves on the Great Lakes, the Sverdrup-Munk-Bretschneider method, adjusted for fetch width, appeared best. A study was started to relate 1,000-millibar geostrophic wind forecasts to observed surface winds over the Great Lakes.

The TDL also worked on the development of objective techniques to improve forecasts of storm surges—changes

Severe flooding isolating farmstead.

in water level caused by atmospheric disturbances. The approach was based on a physical-statistical relationship. Through such an approach, the relationship of extratropical storm surges along the coasts to the offshore oceanic circulation can be determined. A similar relationship for the wind setup on Lake Erie can also be derived. Observed and calculated astronomical tides and storm surge data have been collected for eight east storm stations. These data will be used to develop a computer technique for forecasting extratropical storm surges along the Atlantic coast.

With regard to storm surges on the Great Lakes, TDL in FY 69 derived forecast equations for the wind setup on Lake Erie at Toledo, Ohio, and Buffalo, N.Y., and tested the equations on dependent and independent data with encouraging results. This method uses sea level pressure at nearby NMC grid points to forecast the wind setup by means of screening regression.

A study effort to develop forecast techniques for wave and surf conditions over sandbars at the mouth of the Columbia River and at the entrance to Yaquina Bay, Oreg., was launched late in FY 69. This TDL project, contracted to Oregon State University, involves identification of wave direction, wave period, wave height, tidal flow, river outflow, and pertinent weather conditions that make bar crossings hazardous. Movements, intensities, and any other particularly critical characteristics of weather systems that generate hazardous wave conditions will be evaluated to permit test forecasts for such conditions. By the end of the fiscal year, plans had been completed for installation of an 85-foot Totem buoy off the Oregon coast.

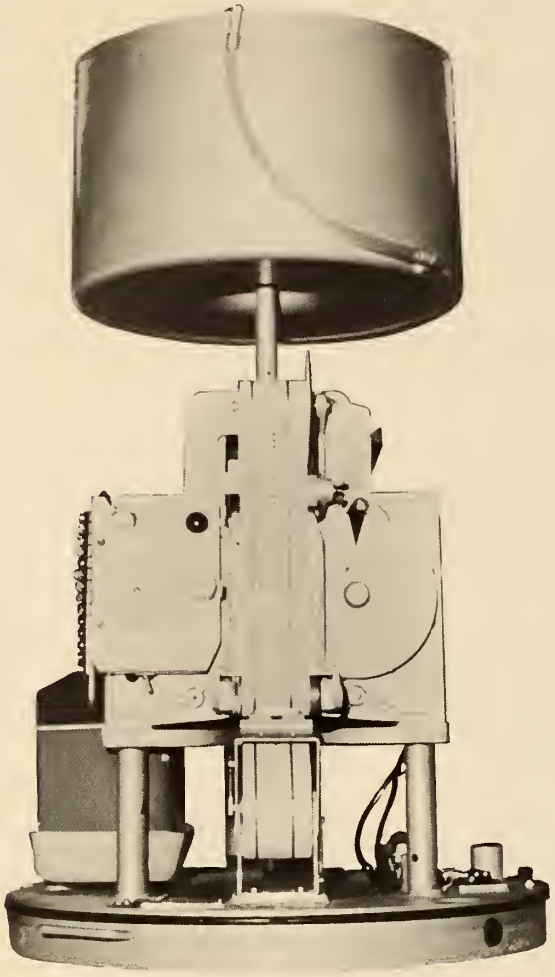
Storm Surges

The RL's Atlantic Oceanographic Laboratories (AOL) continued development of numerical models to improve ESSA's storm surge prediction service. In FY 69, research was initiated to incorporate bottom stress time-history in the linearized equations of motion for storm surges in an effort to formulate a physical model of bottom stress which has a firm mathematical basis. Treatment in the past has been limited to initial values of the known driving forces or to a differential form containing only a limited amount of their time-history. The new approach is based on the premise that any fluid in a basin, which is subjected to driving forces, will reflect the history of the driving forces during its entire transient state. This approach suggests that bottom stress be treated in an integral form that incorporates time-history of the driving forces. Preliminary results from use of an integral form are significantly different from those using a differential form, or only initial values, of the driving forces.

RIVER AND FLOOD PREDICTION AND WARNING

Service Programs

On the average, the American economy suffers an annual loss of 60 persons and 1 billion dollars in property damage from floods. A primary responsibility of ESSA's WB river and flood forecast and warning programs is to reduce these severe losses by warning the public of potentially dangerous river conditions.



Punched tape telemetering rain gage.

Forecasts with a lead time of only a few hours can be effective in reducing property losses and in saving lives. For example, protection measures, taken as a result of WB warnings, decreased the total property damage by about two-thirds during the spring 1969 record-breaking floods in the Northern Plains States.

In addition to forecasts of floods, the WB issues regular forecasts of river stages and flow volumes for many water-related activities—ranging from sports fishing to river transportation. Approximately one-sixth of the Nation's freight is moved by river and lake barges so that forecasts of river conditions affect the operations of this important transport system.

Those responsible for planning and operating water-use systems need streamflow forecasts to operate those systems effectively and efficiently, be they farmers dependent upon irrigation or multimegawatt hydroelectric network operators. Indirectly, every segment of the Nation's economy is affected by the quality and quantity of river forecasts.

Data Collection

To produce river forecasts, hydrologists require a considerable amount of real-time data. The basic sources of these data are networks of precipitation and river-stage reporting stations. Most of these networks are funded for and operated by the WB, but many are funded and operated through cooperative agreements with other Federal, State, and local agencies. In addition to data network information, forecasts or observations are furnished by other WB or ESSA elements. These range from forecasts of precipitation and temperature to the data gathered by radar and satellites. For instance, information on the extent of snow fields is produced operationally by ESSA's National Environmental Satellite Center (NESC). Radar observations are used to define the location and extent and to estimate the intensity of rainfall.

Data are available on a near real-time basis from 7,000 network stations which report to one of the Weather Bureau Offices (WBO) designated as River District Offices (RDO) or to one of those WBOs which collect and relay hydrologic data. In either case, data are then relayed to the appropriate River Forecast Centers (RFC) for preparation of forecasts.

Preparation of Forecasts and Warnings

Although several Federal, State, and local agencies prepare individual forecasts to meet their particular requirements, the primary source of public forecasts and warnings is the RFCs of the WB. These Centers issue routine and flood forecasts for approximately 1,800 points along the country's major rivers; limited number of RDOs, not supported by the RFCs, issue forecasts for some 200 points. Forecasts vary from flash-flood warnings to seasonal snowmelt forecasts.

In addition to producing and disseminating forecasts, the RFCs develop new and better forecasting procedures and correct and update empirical or pragmatic procedures in use. Statistical methods are employed to develop procedures for seasonal snowmelt and for 30-day outlooks and volumetric flows, with heavy reliance placed upon historical data from ESSA's Environmental Data Service (EDS) and the Department of the Interior's Geological Survey.

Presently, a considerable portion of such data are on magnetic tapes or punched cards which are suitable for direct computer analyses. High-speed digital computers are being used by all RFCs. Computers are particularly useful in producing forecasts, especially if the time between the issuance of a warning and the occurrence of the flood is short. Furthermore, large quantities of data necessary to produce river forecasts make the operational real-time use of computers most appropriate.

Dissemination of Forecasts and Warnings

After the RFCs have reduced and analyzed the meteorological and hydrological data and then produced forecasts, these forecasts are transmitted to the affected RDOs. The public is informed through the regular news media or in emergency situations by the Office of Civil Defense, by

ESSA meteorologists appraising heavy snow cover in the Red River Valley of North Dakota.

State and local police agencies, or by other public safety officials. The time lapse between actual observations of rainfall and river conditions and issuance of the forecast or warning seldom exceeds 5 hours. Considerable progress is being made toward reducing this time lapse through the use of automated gages and communications devices. Eventually, improved meteorological forecasts of heavy rain may be used instead of actual observations. Presently, weather forecasts are being used as criteria for internal WB alerts of possibly dangerous river conditions.

Information Services

Those responsible for planning and designing hydrologic structures have a great need for hydrometeorological analysis on which to base their decisions. The WB provides such service to other Federal agencies through contractual arrangements; this information is also available to other users through technical publications. These hydrometeorological studies relate historical records of precipitation to the resulting hydrologic events; the reliability of the results is dependent upon the length and quality of the historical records. Both empirical and statistical methods are employed.

Research and Development Programs

The responsibility for ESSA's R&D programs in hydrology rests with the WB's Office of Hydrology. Most in-house research is centered in the Hydrologic Research and Development Laboratory at WB Headquarters in Silver Spring, Md. The work of the Laboratory is mission-oriented, with its primary objective to develop and test improved techniques for application in operational river forecasting. Most research is accomplished at the Laboratory; however, certain projects are contracted to universities, research corporations, and other ESSA components.

Hydrological Models

Considerable effort during the reporting period was devoted to the development and testing of conceptual hydrologic models which provide a continuous simulation of the streamflow hydrograph. The well-known Stanford Watershed Model is being tested for its applicability to operational forecasting. The Streamflow Synthesis and Reservoir Regulation (SSARR) Model, originally developed by the staff in the Corps of Engineers Office in Portland, Oreg., and used by the Portland RFC in operational forecasting for the Columbia River Basin, is also being tested. These Models are being tested on several river basins in the United States with widely varying climatic characteristics.

Snow and Snowmelt

Snow measurement and snowmelt problems received considerable attention by the Office of Hydrology during the last 2 years. In cooperation with the Department of Agriculture's (DOA) Agricultural Research Service (ARS), the

metamorphosis of snow is being studied at the ARS Sleepers River Experimental Watershed in Vermont, with special attention being given to the energy budget for computing rates of snowmelt. A study has also been initiated at this site to determine effects of exposure on precipitation gage catch and to develop methods for obtaining "true" ground precipitation (especially of snow). Simulation studies of snow accumulation and ablation processes in conjunction with the Stanford Watershed Model are being made. Additional test areas besides the Sleepers River Experimental Watershed include the Rock River Basin of Minnesota and Iowa, and several basins in the Rocky Mountain States.

Evaporation

The Hydrological Research and Development Laboratory has also been quite active in research efforts directed toward evaporation. At the request of the World Meteorological Organization (WMO), comparative studies have been made of evaporation instruments in use to assist in the selection of an interim international reference evaporimeter. Tests of an experimental insulated evaporation pan show promise of being superior to any evaporimeters now in use. This pan will also provide reliable daily estimates of incident all-wave radiation.

The Laboratory is also cooperating with the Geological Survey in a study of evaporation from the Salton Sea in California. The observational phase of this project has been completed; the study is now in the data reduction stage.

Radar Precipitation Analysis

One of the most difficult problems confronting operational hydrologists is the determination of integrated values of various hydrologic parameters over fairly large areas. Extrapolation of point values can frequently lead to gross uncertainties if the parameters being estimated are not continuous in time and space, such as precipitation which occurs from thunderstorm or other convection activity.

Radar is the ideal device for determining the where and when of rainfall. The National Severe Storms Laboratory (NSSL) at Norman, Okla., has developed a method which produces a digital representation of the radar image for direct input into a computer. The amount of precipitation is determined by relating the echo intensity to the precipitation rate. Consequently, periodic radar scans can be added or integrated over the entire hydrologic range of the radar—about 100 nautical miles—to produce a time-depth-location estimate of rainfall in near real-time and in computer-compatible form. The system method records the echo intensity of each 1-mile increment of radial distance for each 2 degrees of azimuth. These 1,440 discrete observations, representing one full sweep of the radar, are each integrated values of the radar response for the increment of area; they are recorded on magnetic tape almost instantaneously and transmitted to a computer by data telephone and data links.

A test conducted at Fort Worth, Tex., during the summer of 1969 proved the operational feasibility of such a system. Rainfall amounts computed from radar data were found useable for the river forecasting program, permitting the generation of river forecasts directly from radar information. Additional tests using two or more radars are planned. From these extensive tests, improved and more sophisticated methods of relating radar echo intensities to precipitation rates should result.

Some rather elaborate studies of radar attenuation were made at the RL's Gunbarrel Hill test site near Boulder, Colo., by the Wave Propagation Laboratory (WPL). In these experiments, both vertical-pointing and horizontal radars were used to examine rainfall intensities and distribution along an 11-kilometer path. Because precipitation rates are dependent upon the fall velocity of raindrops, the vertical-pointing radar should furnish an additional dimension to radar study of rainfall. Additionally, because radar impulses of different wavelengths (frequencies) react differently to the same rainfall situation, multifrequency radars may be used in future investigations.

The WPL is also involved in radar precipitation analysis through research projects to improve remote sensing capabilities to meet the environmental monitoring requirements of hydrologists and weather observers. The problems of evaluating the effects of meteorological events over sizeable areas will require the use of remote sensing devices. Progress toward that objective is underway.

Other R&D Projects in Hydrology

R&D funds are utilized to support contract research in hydrology, with certain funds having been transferred to the Systems Development Office (SDO) of the WB and to the Environmental Sciences Group (ESG) of the NESC to conduct hydrologic research. Other areas of in-house research being supported in SDO include the collection and retransmission of hydrologic data by geostationary satellite and development of a flash-flood alarm gage.

Contracts for hydrologic research have been awarded to various universities and research corporations. Areas of contractual research include: (1) ground water influence on streamflow in mountainous areas; (2) snowmelt process modeling on a combined analog-digital computer; (3) snow fence use for shielding precipitation gages; (4) areal extent of snow cover in plains and mountainous areas by satellite; (5) electromagnetic sensor correlation study; (6) rainfall-runoff relationship study in the Fairbanks, Alaska, area; (7) evaporation feasibility studies; and (8) variability study of the unit hydrograph.

Expansion of the Hydrology Program

High on the priority list for expanded program development is the plan to use advanced technology in automation and communication to improve hydrologic data collection and relay by satellite, to reduce and transmit digitized radar data, and to employ airborne remote sensors. Another high priority item is the improvement and expansion of the RFCs. Continuing development of more sophisticated and better forecasting methods is necessary to make improved hydrological services available throughout the country. More detailed, frequent, accurate, and wider selection of forecast products will better serve the Nation.

5 EARTH DESCRIPTION, MAPPING, AND CHARTING

The Earth Description, Mapping, and Charting activity embraces the disciplines of geodesy, geomagnetism, and seismology, and includes aeronautical charting and marine geophysics. Within ESSA, this activity is both a service function and the subject of research and development (R&D) programs pursued by the Coast and Geodetic Survey (C&GS) and the Research Laboratories (RL).

ESSA's service programs in geodesy are concerned with establishing and maintaining horizontal and vertical control points, determined by means of surface, aerial, and satellite triangulation and photogrammetry. These programs provide adequate knowledge of locations and boundaries necessary for the conservation and development of natural resources, for such civil engineering and scientific projects as microwave communication and petroleum exploration, for the national mapping program, for projects of economic significance including the construction of interstate highways, and for control requirements in urban development. ESSA's R&D program in geodesy includes the development of new technology in the fields of satellite and aerial triangulation, photogrammetry, long-range distance measurements, and land and marine gravity measurements.

Service programs in geomagnetism support ESSA's efforts in the compilation and production of charts indicating the distribution of strength and direction of the earth's magnetic field. Such programs provide geomagnetic data and information required for land surveying and forecasting of radio propagation conditions, and assist in the processing, analysis, and dissemination of data. The R&D programs in geomagnetism are designed to improve the capability for both prediction of the geomagnetic field with its variations in space and time, and the achievement of a better understanding of the origin of these effects and their relationship to other phenomena of the physical environment. To attain these goals, ESSA supports research to improve instruments and systems, to develop better methods and procedures for improved data gathering and analysis, and to investigate the interrelationship between the magnetic field and other parameters. The data for these studies are obtained from magnetic observatories of the world, and from local observatories on land, at sea, by aircraft, and by satellites.

The service programs in seismology are concerned with the impact of earthquakes on the Nation and with the expansion of knowledge on the structure and physical properties of the earth's crust and deep interior. It is a multifacet program, involving the operation of a seismic observatory network to record seismic waves transmitted through the earth; location and publication of earthquake hypocenters; collection, cataloging, and publication of earthquake damage and intensity data; operation of an accelerograph network to record strong earth motions in earthquake-source regions; operation of tiltmeters and strainmeters in earthquake-prone regions; and the operation of a tsunami warning system. To assist in the acquisition of seismic data and the distribution of seismic information to the public, ESSA maintains a World Data Center for Seismology and a National Earthquake Information Center (NEIC). The World Data Center for Seismology collects final seismic data from international seismographic observatories and disseminates them to requesting users. The NEIC attempts to increase public awareness of the nature and extent of earthquake hazards. The R&D program is oriented toward the design and development of new instruments and systems, development of new analytical techniques to obtain more accurate information about earthquake hypocenters and source mechanisms, development of accurate travel times of seismic waves, and a better understanding of the earth's structure and physical properties. An important phase of ESSA's R&D program is the study of economic and life hazards in earthquakes and the development of guidelines to minimize the impact of destructive earthquakes.

ESSA has responsibilities for the production and distribution of aeronautical charts and for the development of improved cartographic methods. The service program in aeronautical charting involves all operations required to produce and maintain the aeronautical charts needed for

air navigation in the United States and its possessions. ESSA's research program concentrates on the development of new and the improvement of existing cartographic techniques. This R&D activity includes the development of new production techniques and of new types of graphic display of information.

The role of ESSA in marine geophysics is to gain a clearer understanding of the structure, nature, and evolution of the ocean bottom and the ocean basin boundary. To meet these objectives, studies are instituted in different oceanic regions of the world.

GEODESY

Service Programs

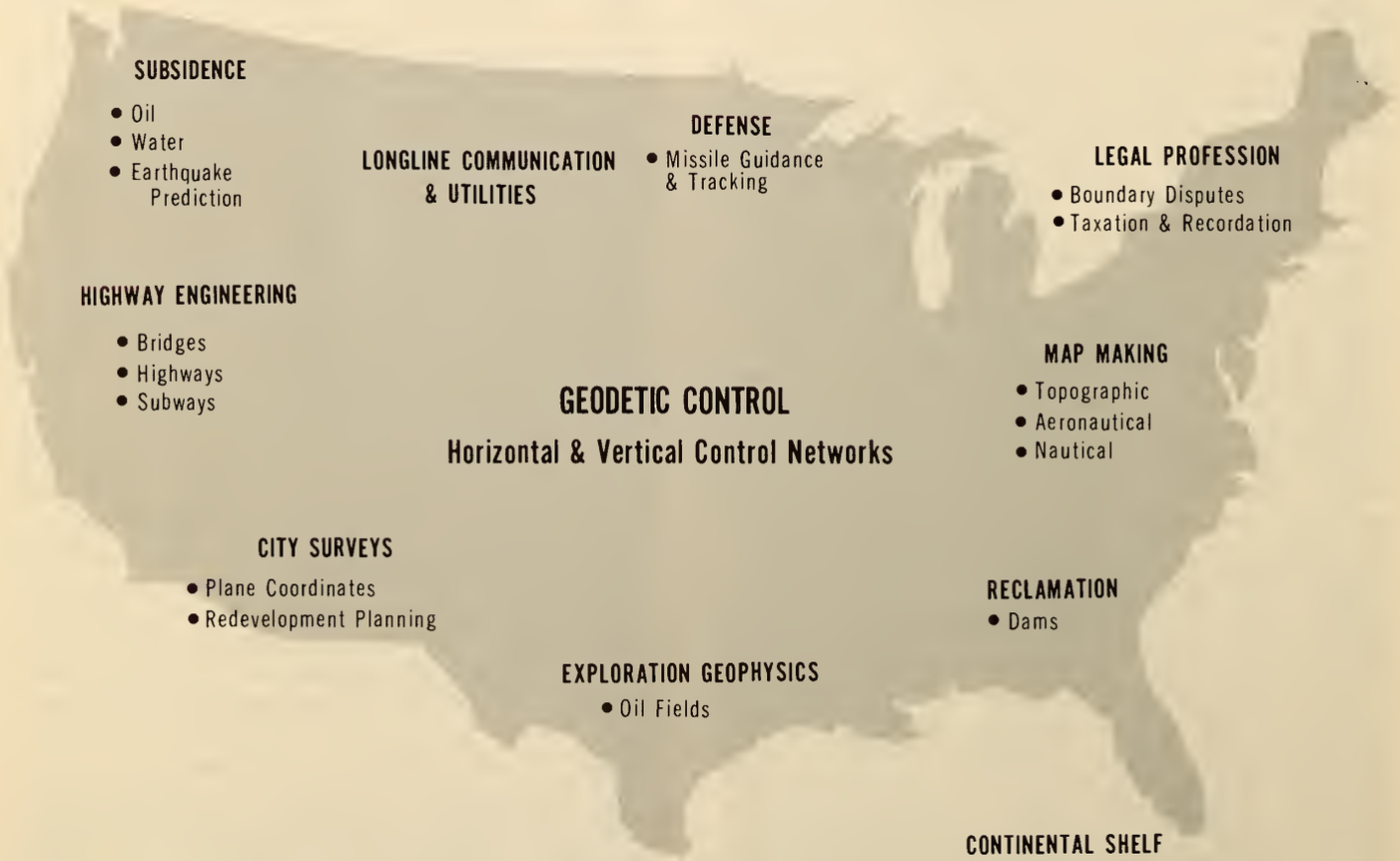
The primary objective of ESSA's geodetic program, which is performed by the C&GS, is the development of fundamental horizontal and vertical control survey networks for the United States and its possessions. These geodetic networks serve as the basis for all engineering surveys required for economic growth and provide homogeneous reference framework for all scientific projects which relate to exact distances and directions on the earth, accurate three-dimensional coordinates referenced to the center of mass of the earth, and ultraprecise reference systems for such geophysical problems as crustal movement, continental drift, and space tracking.

The development of these surveys includes the extension and subdivision of the loops of the networks, continuous maintenance of the survey markers which constitute the permanent monumentation of the networks, and improvement of the overall accuracies of the networks through connections to the worldwide geodetic satellite framework. Both the worldwide and continental geodetic satellite networks, combined with the precise transcontinental traverses, establish a reference framework accurate to one part in a million with respect to points within the network and with respect to the center of mass of the earth.

The photogrammetry program within ESSA provides support to the aeronautical charting, marine navigational charting, oceanographic, and geodetic programs. The Photogrammetry Division, part of C&GS's Office of Geodesy and Photogrammetry, is directly responsible for planning, scheduling, and executing all photogrammetric activities within the C&GS.

Users of Data

The users of geodetic data include Federal agencies, numerous public and private groups within each of the 50 States, counties, and municipalities. Engineers and scientists within these governmental units use the survey data directly for supplementary survey control or indirectly for photogrammetric operation support to large-scale mapping for topographic, taxation, utility planning, boundary demarcation, and many other purposes.



Some applications of geodetic control.

Field Operations

During the past 2 years, the C&GS operated six horizontal control survey parties and three vertical control parties, averaging about 20 men each. These units established 1,500 new permanently monumented and more than 1,200 intersected horizontal control points and determined the elevations for 6,000 new bench marks. In normal operating procedures, approximately 50 percent of the previously established points must be reoccupied. Thus, the total number of geodetic points surveyed exceeded 15,000.

Additional survey data from other Federal agencies and some State groups involved the location of more than 2,800 new points which were adjusted and added into the National Geodetic Network.

To maintain the horizontal and vertical control networks comprised of more than 120,000 monumented triangulation stations and approximately 320,000 bench marks, 18 one-man C&GS field units systematically search for and inspect these marks for damage resulting from natural or manmade causes, install highly visible witness posts and signs, and update the descriptions on these survey marks. If a station mark is reported or found to be in danger of destruction, the station is relocated nearby. This preventive maintenance action saves the Federal Government hundreds of thousands of dollars. A triangulation station can be moved for less than 10 percent of the cost of reestablishing a destroyed station. The comparative cost of moving a bench mark is 25 percent of the basic cost of a new survey.

Many States and some of the rapidly growing urban areas have sought ESSA's assistance in the establishment of more precise and closer spaced control. Surveys for the States of Rhode Island and Vermont; the cities of Houston, Tex., and Albuquerque, N. Mex.; and the counties of Monroe, N.Y., and Honolulu, Hawaii, were completed during the past 2 years.

The State Highway Department of Rhode Island requested the C&GS to establish primary control throughout the entire State, with 2- to 5-mile spacing between points.

The State of Vermont required a survey for the northern portions of the State; this work by the C&GS was coordinated with the Vermont Base Map Organization Committee. The survey control is to be used for a large-scale photogrammetric mapping project of the entire State.

A first-order, class I triangulation project was completed by the C&GS in cooperation with the city of Houston; the project interconnected other surveys and updated previously monumented points.

The Middle Rio Grande Council of Governments in New Mexico asked the C&GS to provide a first-order, class I triangulation network for metropolitan Albuquerque and 3 adjacent counties, with spacing of 2 to 5 miles in the metropolitan area and 4 to 6 miles in the adjacent counties.

A first-order, class I triangulation network, spaced at 2- to 5-mile intervals over all of Monroe County, was established by the C&GS.

The State of Hawaii requested the C&GS to undertake a survey to establish a first-order, class I network triangulation over the entire island of Oahu.

Precise Alinement Survey

The C&GS was requested by the Air Force during the reporting period to establish a precise alinement survey as a reference for the high-speed sled track at Holloman Air Force Base, N. Mex. Similar surveys were previously conducted in 1956–57 and 1962. This track, which is approximately 35,600 feet in length, is in relatively flat desert terrain. Increased velocities and improved sleds make it necessary to reestablish the reference line and obtain the highest precision possible. A special type of triangulation network was designed which would provide the maximum strength for this precise alinement. To provide redundancy and maximum statistical evidence for accuracy, two identical networks were measured. These networks, parallel to each other and to the track, were spaced about 82 and 100 feet, respectively, offset from the track. Final results show that the uncertainties of alinement throughout the full length are less than 3 millimeters.

Crustal Movement Surveys

An intensive program of monitoring slippage and strain accumulation along the San Andreas Fault of California was continued. Results show a continuing horizontal slippage of a few millimeters per year along the Hayward Fault of California in the East Bay area, and only 1 to 2 centimeters per year along the San Andreas Fault in the vicinity of Hollister and in the Salinas River Valley. The releveling program in the San Joaquin Valley defined the regions of maximum subsidence which during the past few years has been averaging almost 30 centimeters annually.

The basic continental releveling program, designed to furnish information on the broad regional vertical movements associated with tectonic processes, continued. During the past 2-year period, more than 5,000 miles were releveled.

High-Precision Transcontinental Traverse

The C&GS initiated a program for the measurement of a High-Precision Transcontinental Traverse Network, criss-crossing the conterminous States in FY 62. The completed Network will consist of five primary north-south lines and three primary east-west lines, with extensions to connect the framework to geodetic satellite triangulation stations. This precise survey will provide a scaler line for the Worldwide Geometric Satellite Network; three other scalers on three different continents will also be used. The Transcontinental Traverse Network also will serve as a control framework for the basic triangulation nets. During FY 68 and FY 69, 3,675 kilometers (about 2,275 miles) were measured by C&GS survey parties and about 200 kilometers (about 135 miles) by the U.S. Army Topographic Command (USATOPOCOM); more than 50 percent of the eventual 22,000-kilometer (13,640-mile) network has been measured.

Worldwide Geodetic Satellite Program

The C&GS has been engaged in the worldwide, 44-station, Passive Geodetic Explorer Satellite (PAGEOS) geometric

network since July 1966. This network is part of the National Geodetic Satellite Program, established through the joint efforts of the National Aeronautics and Space Administration (NASA) and the Departments of Defense (DOD) and Commerce (DOC), and in cooperation with the Federal Republic of Germany, United Kingdom, Australia, and other nations on whose territories camera stations of the world network are located. This effort is the largest, most extensive, cooperative international geodetic program ever undertaken.

At the beginning of FY 68, 13 BC-4 camera systems were engaged in the data acquisition phase of the program: four operated by the USATOPOCOM, seven by the C&GS, and one each by the United Kingdom and Germany.

By the end of FY 69, five additional camera units had been added to assist in meeting the proposed completion date of June 1970: three BC-4's, one each operated by the C&GS, South Africa, and Germany, and two PC-1000's operated by the Air Force. An employee from the C&GS is attached to each team except those operated by USATOPOCOM. Overall technical responsibility for the program, which includes the task of maintaining all camera systems and establishing and maintaining accurate time at all locations, is provided by the C&GS.

Gravity and Astronomy

The gravity field of the earth provides the alinement framework necessary for geodetic instruments; the figure of the earth is expressed in terms of the gravity potential at the surface and above. Measurements of the intensity and direction of the gravity field, using gravity meters and astronomic instruments, are applied in: (1) refinement of the horizontal and vertical control networks; (2) development and operation of inertial guidance and navigation systems; and (3) studies of the earth's internal and crustal structure in connection with the search for underground resources and analysis of earthquake mechanisms.

Land gravity surveys were conducted in the vicinity of Washington, D.C., to determine deflections of the vertical at the U.S. Naval Observatory and two C&GS astronomic observing sites. Area gravity coverage was extended by survey operations in central Oklahoma.

Marine gravity surveys were made in the Gulf of Maine and along the Florida-Georgia coast, continuing surveys of the east coast Continental Shelf, and over a portion of Norton Sound on the Alaskan Continental Shelf. Several gravity tracklines were measured by C&GS ships in connection with various oceanographic projects; an underwater gravity survey was completed in the area west of Cape Flattery, Wash.

Extensive profiles of the geoid made possible by recent gravimetric and astronomic surveys were completed in various regions of the United States. These geoidal profiles are important for figure-of-the-earth studies and are essential to relate scale and orientation of the satellite triangulation system to a new North American Datum. Detailed maps of the geoid were compiled for New Mexico, Arizona, and the New England States.

Two of the five latitude observatories of the International Polar Motion Service at Gaithersburg, Md., and Ukiah, Calif., were operated by C&GS throughout the 2-year reporting period. These observatories provide up-to-date information on the small movements of the earth's axis within the body of the earth. Characteristics of this polar wandering reflect the internal strength and constitution of the earth. The measured displacements of the pole are applied to corrections for precise astronomical observations, to studies of the variations in the rate of rotation of the earth, and to a more precise determination of UT1 time—that is, universal time corrected for the mean position of the pole.

Aerial Photography

Two aircraft were used to obtain panchromatic, infrared, and color aerial photography with wide-angle and super-wide-angle single-lens, precision metric cameras. Two C&GS aerial photographic missions accomplished 60,000 kilometers of aerial photography during the reporting period. The primary areas of photographic interest were coastal areas and commercial airports. Special-purpose aerial photography was obtained to provide tide-controlled infrared photography for the accurate location of the mean high-water line, and to use tide-controlled color photography at low water for the compilation of rocks, obstructions, and nearshore detail, and for the location of navigational aids and other features of importance to the mariner.

Photogrammetric Operations

Shoreline Mapping Parties—photogrammetric field survey units of the C&GS—accomplished coastal mapping, chart maintenance, and tidal current survey projects along the Atlantic and Pacific coasts. These Parties provided photohydro support to those C&GS vessels and shore-based launch parties that were engaged in hydrographic operations, installed and monitored tide staffs for tide-controlled infrared photography, recovered and premarked control before aerial photography, field-edited shoreline surveys and chart drawings, and inspected marine facilities for the preparation of Small-Craft and Intracoastal Waterways Charts. Aero Survey Parties were assigned to survey airports and locate aids to air navigation for the Federal Aviation Administration (FAA).

Coastal Mapping

The Photogrammetry Division's activities provided detailed mapping information for nautical chart construction and maintenance, conducted shoreline surveys and supplemental control for hydrographic operations, furnished locations of landmarks and aids to navigation, and supplied reductions of tidal current measurements. In the past 2 years, about 225 shoreline maps with specially prepared aerial photographs and related photogrammetric data were furnished to C&GS vessels for use in hydrographic operations. For chart maintenance work, a total of 825 regular charts, Small-Craft Charts, and basic map drawings were corrected from new aerial photography.

Color photography was used for the photogrammetric location of over 1,200 aids to navigation; a similar number of landmarks were located on map and chart drawings. Over 300 special Airport Obstruction Charts were compiled and published for the FAA; included in the number were air navigational facility maps and noise abatement mosaics.

Coastal Inundation Mapping

Under a reimbursable agreement with the Department of Housing and Urban Development (HUD) made in May 1969, ESSA initiated a pilot project in coastal flood studies. This cooperative program effort involves the Photogrammetry Division of C&GS, other components of ESSA, and other Federal and local Government agencies. Flood stage information will be collected from tidal observations of the C&GS's Oceanography Division and from the archives of other agencies. The Weather Bureau's (WB) Office of Hydrology will furnish much of the hydrological and meteorological analysis. Coastal inundation mapping and surveying, required for HUD's flood insurance studies, will be provided by the Photogrammetry Division.

Coastal Boundary Surveys

The State of Florida entered into a reimbursable agreement with C&GS during the latter half of FY 69 for the determination of tidal datum planes and for the mapping of both the mean low-water and high-water lines. The work will require 5 or 6 years, depending upon adequate funding, and will involve the participation of the Geodesy, Oceanography, and Photogrammetry Divisions.

Buffalo Aircraft

During FY 69, Congress authorized ESSA to accept the transfer from NASA of a DeHavilland Buffalo DHC-5 airplane for operational and research uses. The aircraft was extensively modified for aerial metric photography to support the C&GS's mapping and charting services; the aircraft became fully operational during the spring of 1969 and saw service in the Southern States, Puerto Rico, and Alaska. Three mapping camera stations are equipped to permit simultaneous infrared, panchromatic, and color photography; when desired, simultaneous photography at different scales is possible by using normal-angle, wide-angle, and superwide-angle cameras. The three camera stations and operational capability of the aircraft are considerably superior to those available to the C&GS in the past.

Supplemental Control by Analytical Aerotriangulation

Analytical aerotriangulation permits the accurate determination of the ground coordinates of objects appearing on a block of overlapping aerial photographs, using relatively few known ground positions. The digital calculation approach depends on comparator measurements of pertinent image positions on each photograph. This approach contrasts with the analog approach where measurements are made with a stereoscopic plotting instrument. The analytical aerotriangulation photogrammetric system, referenced to the classical geodetic datum of the United States, has a statistical accuracy that range from less than 1 inch to 1, 2, or more feet, depending on the size of the uncontrolled area and the height of the photography.

ESSA DeHavilland Buffalo DHC-5 aircraft supporting the C&GS's mapping and charting services.

Presently, it is technically and operationally feasible to determine photogrammetrically the geodetic positions and elevations of an unlimited number of objects on the ground with a root-mean-square accuracy of 3 feet for premarked points (6 feet for natural objects) in blocks of 5,000 square miles or larger, based on classical geodetic horizontal and vertical control only on the periphery of the area and to about a dozen points of known elevation scattered within the area.

A comprehensive test of the analytical aerotriangulation system was conducted by the C&GS in an area of 2,100 square miles in Kansas; a root-mean-square error of 2 feet horizontally and vertically was obtained. A cooperative test conducted by the C&GS and the Geological Survey on a pilot project area of 1,600 square miles reported results with a horizontal error of 2.1 feet and a vertical error of 1.7 feet.

During the last 2 years, extensive revisions and improvements were made to existing computer programs. The 180 Photograph Model Program developed for the STRETCH computer was revised and enlarged to accommodate blocks which might include 600 photographs for ESSA's on-line computer.

Automatic Drafting Machine

A Swiss automatic drafting machine installed at the C&GS in August 1968 has been successfully and economically used in limited operations. This drafting machine does automatic drafting and plotting directed by a small on-line computer using magnetic tape. Drafting can be either penciled, inked, or scribed lines by either linear, circular, or cubic interpolation. The machine has great capability for plotting position data and will draft lines at speeds as great as 120 inches per minute to an accuracy of 0.03 millimeters. The drafting machine has been used to produce commonly used map projections, plots of geodetic and geophysical data, star charts for satellite geodesy use, bases for special-type charts, and cadastral survey plots.

Manual of Color Aerial Photography

The Photogrammetry Division of C&GS made significant contributions to a *Manual of Color Aerial Photography* published under the sponsorship of the American Society of Photogrammetry. This *Manual* was a cooperative effort involving contributions from professional photogrammetrists in the Government, universities, and industry.

Research and Development Programs

The R&D programs in geodesy within ESSA were conducted by both the Geodesy Division of C&GS and the Geodetic Laboratory of RL until July 1, 1968; at that time, the Geodetic Laboratory was transferred to the C&GS as its Geodetic Research and Development Laboratory. This action collocated all satellite geodetic research with the operating geodetic program. Reporting of R&D projects was consolidated for the reporting period under C&GS.

Trilateration Test Net

A special trilateration study was conducted by the C&GS in cooperation with a Louisiana Department of Highways project. The network consisted of 19 primary points covering an area of 500 square miles in the northwestern portion of the State. Two independent surveys were made—the first by conventional triangulation techniques, and the second by trilateration with all lines measured with the laser Geodimeter. A complete analysis of the two methods was made. Adjustments indicate that the standard error of position determination is much less by the trilateration technique, perhaps at a ratio of one to four. A final evaluation will cover the economy of field operations, efficiency with which the measurements can be made, overall accuracy attained, and utility of the final adjusted data for further local extension of survey operations.

Refractive Index of the Atmosphere

Research has been performed on the improvement of techniques for the measurement of the refractive index of the atmosphere through which the Geodimeter measurements are made. One finding verified that when the difference of elevation of the end points of a line is large, but known accurately from connections to precise leveling, the refractive index along the line may be determined by making simultaneous vertical angle measurements at the ends of the line, bracketing the time when Geodimeter measurements are made. The contribution of error or uncertainty for this effect has been reduced to much less than one part per million. The technique has given such satisfactory results that cost reductions were made by eliminating midpoint balloon temperature measurements and by reducing the total number of Geodimeter measurements within the basic traverse figure.

The Wave Propagation Laboratory (WPL) and the Institute for Telecommunication Sciences (ITS) of ESSA's RL have developed distance-measuring instruments, using two optical wavelengths that automatically compensate for the atmospheric reflective index.

Time Studies

Timing is the single most important item in the data acquisition phase of the geometric satellite program. Unless all stations observing an event observe simultaneously within a few microseconds, the observations are useless.

At the beginning of FY 68, time was maintained at field units by a hand-carried portable time standard sent to each field station every 6 weeks. The portable clock was calibrated before and after each trip at the U.S. Naval Observatory in Washington, D.C.

A new method for transferring time by two-way radio transmission through synchronized-orbiting satellites—Applications Technology Satellites (ATS) 1 and 3—was developed by C&GS and the National Bureau of Standards (NBS). This method was used whenever remote stations could see one of the satellites. The results are accurate to at least ± 10 microseconds.

The use of long-range aid to navigation—Loran-C—radio broadcasts was pursued, with equipment and proce-

dures developed to satisfy program needs. As Loran-C chains around the world became synchronized, this method proved usable to accuracies of ± 10 microseconds. Timing was being controlled at seven sites by this method by the end of FY 69.

Development of a system to transfer time by means of satellite-borne clocks in a polar orbit was also initiated during the reporting period. This system was particularly needed for isolated Antarctic stations where no other timing clock types were possible. This method, the Satellite Time Recovery System (STRS), provides an accuracy that is better than 50 microseconds.

Reduction of Satellite Data

Intensive research has been conducted by the C&GS in the analysis of all types of errors associated with the reduction of geodetic satellite data. A statistical comparison of residuals from the mathematical adjustment of the comparator measurements of star and satellite images on photographic plates revealed a systematic bias related to the time of day when the measurements were made and probably related to thermal-loading effects within the comparator. A review of the design of the Mann Comparator disclosed that the plane of the measuring mark, being close to the viewing system, is about 6-centimeter distant from the plane of the photograph being measured. A structural change was made to project optically the measuring mark onto the plane of the photograph. This systematic bias was of the order of 0.3 or 0.4 microns, or equivalent to about one part in a million. Six comparators used in the program were modified; the plates previously measured were scheduled for remeasurement.

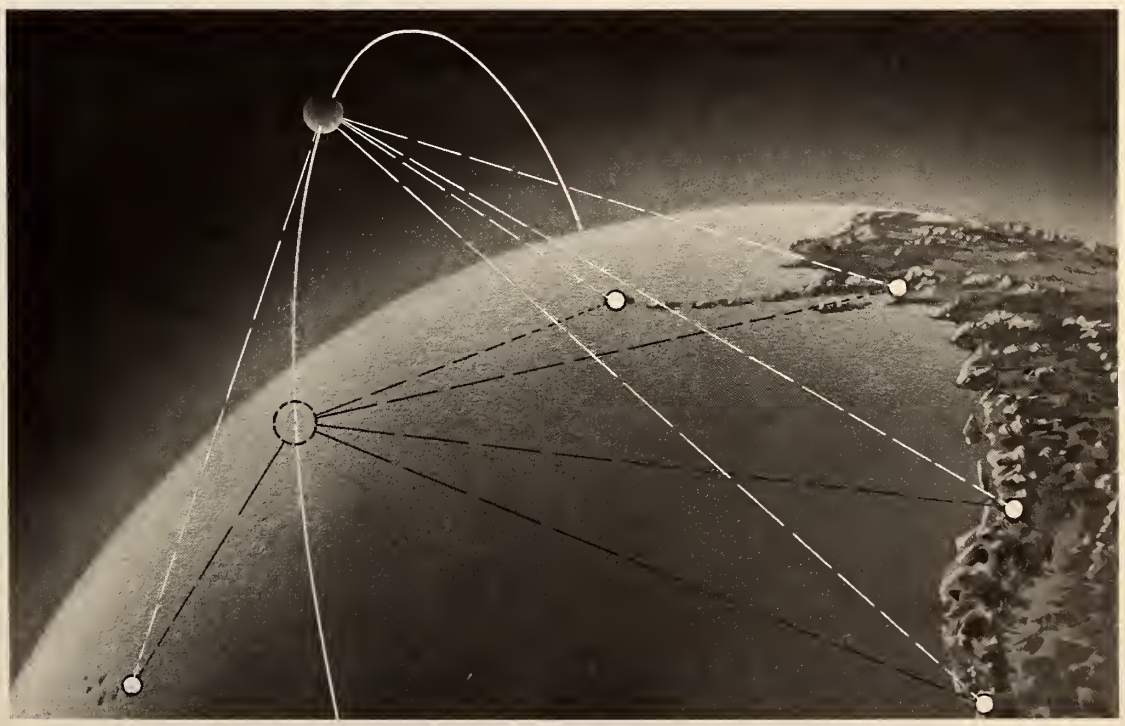
Satellite and Terrestrial Gravity Combined

Special investigations have been made by the C&GS to combine satellite and terrestrial gravity data for a more exact determination of the geopotential. Instead of using the expansion in spherical harmonics, the geopotential is represented by a simple layer distributed over the surface of the earth. Existing gravity anomalies are combined with density values of this surface layer as determined from Baker-Nunn camera observations.

New Adjustment of the North American Datum

One of the major problems confronting geodesists for many years is the requirement for an eventual readjustment of the horizontal control networks of North America. With the availability of the Worldwide Geometric Satellite and the High-Precision Transcontinental Traverse Networks, an eventual long-range readjustment program is being planned. Because the fundamental mathematical approach to the task differs greatly from any prior adjustment, the project requires the adjustment of new measurements of much higher precision, rather than a revision of the older classical triangulation networks.

ESSA has requested the Division of Earth Sciences of the National Research Council (NRC), National Academy of Sciences and National Academy of Engineering (NAS/NAE), to make a feasibility study of this adjustment problem; a panel was selected and a published report is expected in FY 70.



Artist's conception of the extension of the North American triangulation network to Hawaii by means of geometric satellite geodesy.

GEOMAGNETISM

Service Programs

ESSA, through its C&GS component, operates 14 standard magnetic observatories in the United States, Puerto Rico, Guam, and the Antarctic to obtain records of long- and short-term changes in the intensity and direction of the earth's magnetic fields. A fifteenth observatory, Plateau Antarctica, was discontinued as planned after 3 years of operation. All observatories are funded by ESSA except for the two in Antarctica funded by the National Science Foundation (NSF). Each observatory continuously monitors the fluctuation in the earth's local magnetic field. Similar data are obtained for other parts of the world by approximately 175 observatories; these magnetic data are exchanged between countries.

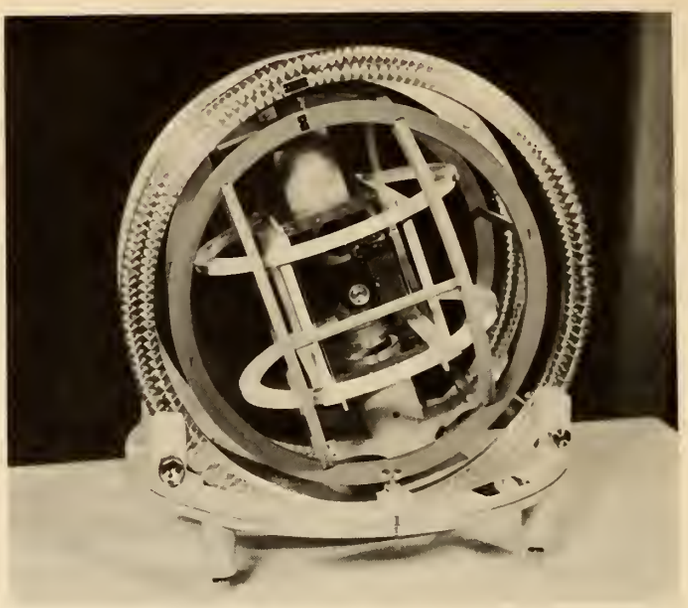
Additional basic research describing the distribution of the earth's magnetic field in time and space to identify sources and variations in strength of the magnetic field was undertaken by the Earth Sciences Laboratories (ESL) of RL during the past 2 years.

At frequent intervals, magnetic data are used to update regional and world magnetic charts which determine correction factors to apply to magnetic field measurements made by land, marine, and airborne magnetic survey parties. The magnetic data are in continuous demand to support studies in atmospheric physics (including the forecasting of radio propagation conditions), in electrical conductivity and composition of the core and mantle of the earth, in monitoring of solar activity, and in mapping of the earth's space environment.

Magnetic declination (angular difference between true north and magnetic north) is indicated on all nautical and aeronautical navigation charts. Correct charting of long-term changes in magnetic declination or variation and in other magnetic elements requires additional magnetic measurements made by C&GS geomagnetic field units at about 175 carefully selected and permanently marked survey points throughout the United States; these points or repeat stations are checked at 3- to 5-year intervals.

Besides repeat surveys, these geomagnetic field units conduct special surveys to satisfy a particular user's request. For instance, a highly detailed survey of a particular location may be made to determine whether the location is free from the contaminating influence of local magnetic materials.

To obtain data over the deep oceans and continental shelves, marine geomagnetic surveys are conducted. During the past 2 years, the C&GS prepared a systems analysis of marine geomagnetism to identify applications of marine magnetic data and to make data acquisition and software recommendations. A significant effort was also directed toward the compilation and identification of backlogged marine geomagnetic data. A marine geophysical mapping survey of a portion of the Alaskan Continental Shelf began during the reporting period.



Coil system and sensor for the rubidium magnetometer used in ESSA's Automatic Standard Magnetic Observatory.

Magnetic Analysis

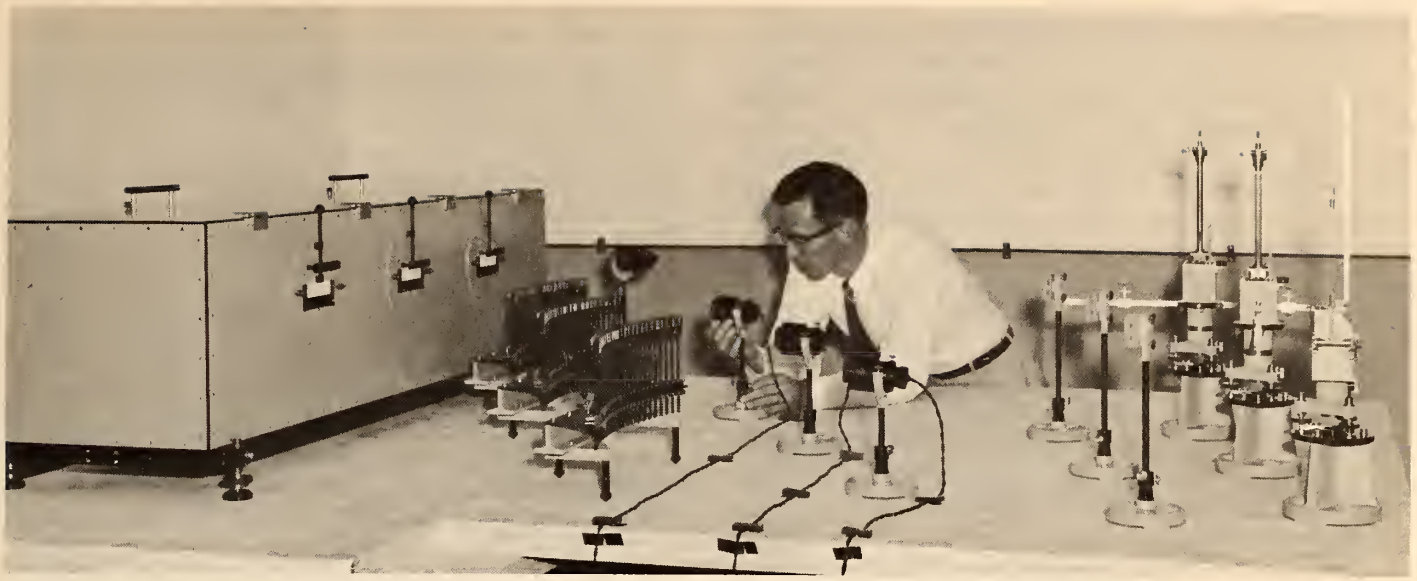
Analyses of magnetic data from field work and observatories—including quality control and evaluation, assignment and application of calibration factors, and evaluation of results for accuracy—are performed to produce high quality data for integral use in magnetic and navigational chart production activities and for the needs of modern science and technology. The purpose of these analyses is to provide information and services to users requiring both static and dynamic descriptions of the earth's magnetic field. Analog data are converted to digital form for use in machine data-handling systems, with output deposited in the World Data Center for Geomagnetism at Rockville, Md., to facilitate broad dissemination.

Information Services

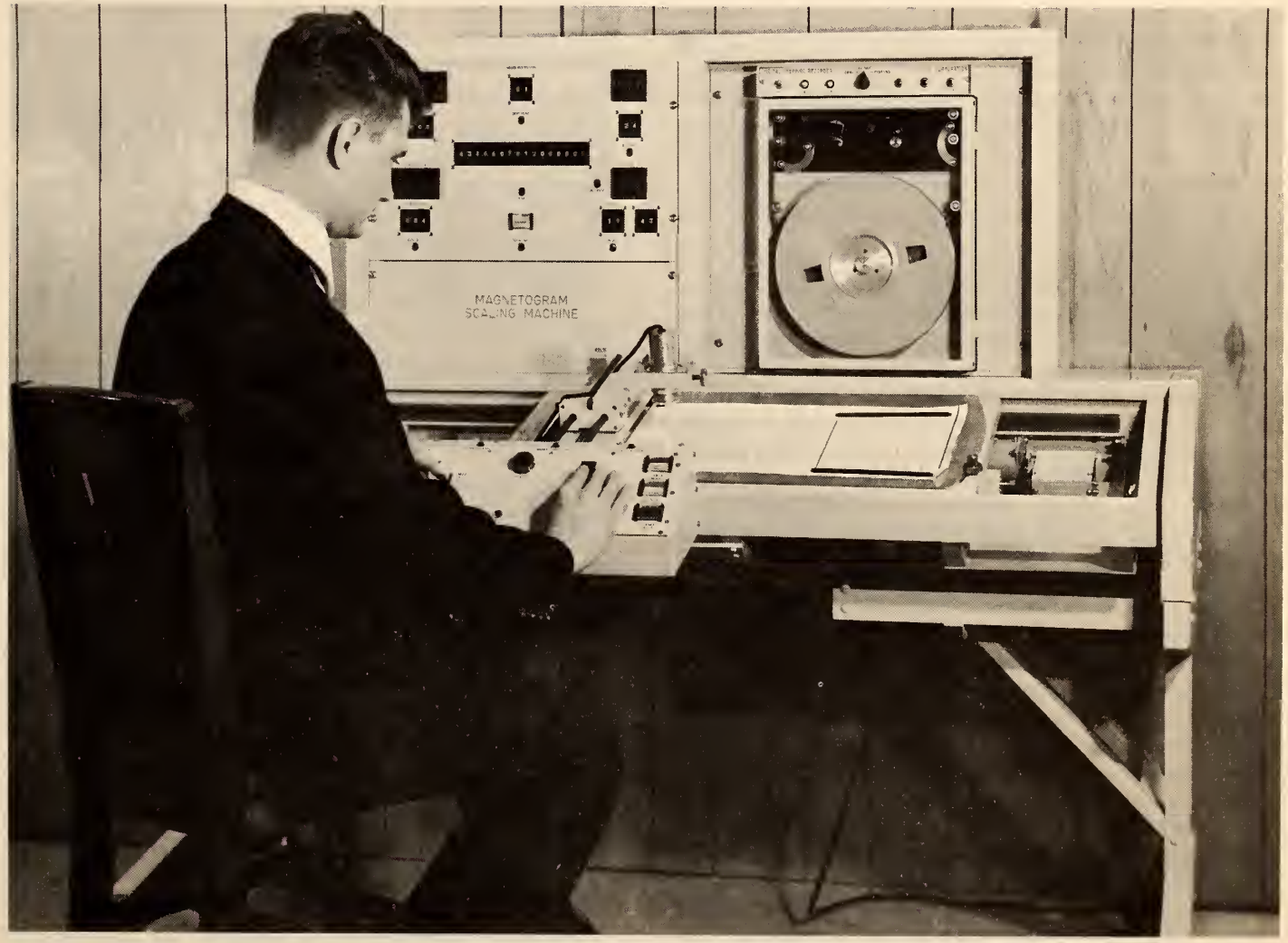
As part of its geomagnetic program, the C&GS prepares magnetic charts of the United States and of the entire world. Each chart series depicts one of five magnetic field elements —declination (or variation), inclination, horizontal intensity, vertical intensity, and total (scalar) intensity—and the distribution of its annual change rate.

Declination charts are recompiled at 5-year intervals to reflect the acquisition of additional data during the interval since the last chart was issued and the effects of long-term secular changes; other charts in the regular series are produced at 10-year intervals. The last complete revision of the regular magnetic chart series was in 1965; preparations are underway for issuance of the 1970 charts in early 1970.

Special charts (for example, declination charts of Central and South America and of the Great Lakes of North America) are prepared on contract as required. Isogriv charts which relate magnetic directions to rectangular navigation grids in the north and south polar regions are also compiled.



Geophysicist adjusting light sources of 3-component rapid-run magnetograph at the Fredericksburg Geomagnetic Center, Corbin, Va.



Magnetogram scaling machine used to convert analog recordings into digital values.

Research and Development Programs

One of the missions of ESSA is to chart and to monitor the earth's magnetic field, its changes, and its intensity across the United States and throughout the world. These data—the basic magnetic field and its secular and transient changes—are required for all types of navigation, for geophysical prospecting of mineral resources, and for scientific studies of the earth's crust and tectonic change within the earth. Magnetic data are also vital to the mapping of the space environment, including the belts of trapped radiation girding the earth and the complex interplay of solar and terrestrial fields and plasmas. Geophysicists at Boulder, Colo., and Rockville are working to perfect both mathematical and physical models of the sources of the earth's magnetic field and its change with time.

Mathematical Magnetic Models

The Geophysics Research Group of the Office of Seismology and Geomagnetism in the C&GS conducted various projects to obtain mathematical descriptions of the main geomagnetic field and its secular change, and to study the faster temporal variations of the field, including those resulting from the action of the equatorial electrojet. Mathematical descriptions were used to compile charts of the main field and its annual change by computerized methods. The temporal variations study gave information for adjusting the main field to epoch. A mathematical model of secular change for the interval 1960 to 1965 was developed; an improved model was sought by a better analytical method for using the data.

Another study by the Geophysics Research Group concerned the mathematical descriptions of the main geomagnetic field, its secular variation resulting from current systems in the earth's core, and with faster temporal fluctuations resulting from current systems in the ionosphere, magnetosphere, and magnetosheath. Mathematical models were developed by spherical harmonic analysis and were in the form of polynomials or Fourier series. A mathematical model of secular change covering the interval 1900 to 1965 was developed; an evaluation of the model was initiated during the reporting period.

The Geomagnetism Division of the Office of Seismology and Geomagnetism investigated the properties and interconversion of low-order model fields, such as dipole and quadrupole models, centered and eccentric. From this study it is anticipated that techniques can be developed to manipulate more complex models and fit them to survey results. Pertinent trigonometric functions were manipulated algebraically; geometric insights including compounding, resolution, and the equivalence of different modes were developed. Work was also done on eccentric dipoles. This study also involved an investigation into the equatorial electrojet by means of bays and similar short-term disturbances. Records taken at equatorial stations were searched for pertinent events, and scalings were made and studied.

Paleomagnetism

A detailed search was instigated during FY 69 into geomagnetic data archives to uncover data permitting harmonic analysis of the magnetic field for the period 1725–1965; such information is important in determining whether a reversal tendency of the earth's field is possible. The ESL began new work in paleomagnetism with the aim of compiling a detailed history of reversals in the earth's field; this work forms the basis for interpreting the implications of the current trend of decrease in the strength of the field.

Paleomagnetism contains many uncertainties and assumptions relating to underlying field reversals. Most prior geomagnetic research has emphasized declination and inclination measurements, and not intensity measurements. Presently, the emphasis is upon intensity measurements before, during, and after a particular reversal through application of new techniques for controlling the atmosphere surrounding the rock inside a furnace, enabling the re-creation of the theoretical environment of the rock at the time of its formation. The past Fiscal Year has seen the near completion of the construction and testing of measurement systems and facilities that are necessary for paleomagnetic research efforts.

Hydromagnetism and Earth's Core

The ESL also initiated a theoretical study of the hydrodynamics of the earth's core and its relationship to the observed magnetic field. The amplification equation of hydromagnetism and the vorticity transport equation, obtained from the Navier-Stokes equation, yielded the requisite simultaneous differential equations describing fluid velocity and magnetic induction in the core.

Studies of long-term secular changes derived from historical studies of reversals mentioned above suggest the possibility of determining fluid motion in the upper 200 or 300 kilometers of the core.

Sources of Earth's Magnetic Field

Results from a model study of sources of the earth's field in FY 68 indicated that the observed field can be accounted for by a centered dipole and 19-radial dipole sources placed at 0.136 earth's radius from the center. During FY 69, success was achieved by ESL scientists in adjusting dipole parameters for 21 dipoles to fit the 1955 Finch-Leaton field of the earth to a root mean square of only 28 gammas. The dipole parameters were then adjusted to fit the secular change for the 1955 Finch-Leaton field to a root-mean-square value of 2.125 gammas per year in the vertical component. This adjustment showed the typical westward drift of approximately 0.15 degrees per year. Work was started for a similar fit to the field and secular change for the new International Geomagnetic Reference Field determined by the International Association of Geomagnetism and Aeronomy (IAGA).

Continuing observations of variations in the absolute geomagnetic field increasingly demonstrated the immediate

need for an accurate, sensitive, and stable magnetometer. An increase in geomagnetic measurement accuracy brings with it the resolution of major questions regarding the physics of the origin of natural phenomena. Because of ESSA's extensive involvement in a wide variety of geomagnetic observations about the world, the ESL scientists continue the development of new, relevant, and refined instrumentation.

During FY 69, a single-line rubidium magnetometer was developed by the ESL. Construction was also completed on a second system. Simultaneous operation of these two systems will establish their accuracy, sensitivity, and stability. Once initial short-term tests have been completed, ESL will operate these two systems at varying separations to define the extent of spatial uniformity of magnetic field variations. These data will serve to describe the nature of the source of the field's variations and the induction effects associated with the areas of study, and will permit more accurate investigations of geopiezomagnetic variations.

Magnetic Spatial Noise

The ESL scientists conducted magnetic spatial-noise studies at the Craters of the Moon National Monument, Idaho; Lava Beds National Monument, Calif.; and Hawaii Volcanoes National Park, Hawaii. These studies involved the analysis of magnetic data in both space and wave-number domains to determine what limitations are placed on the detectability of signals at these high-noise sites. Such data are useful in developing techniques to permit magnetic instrument searches for lava tubes—caverns that could be used for shelter or storage and which, in certain semiarid areas, are the only water reservoirs. Additionally, spatial studies conducted on Hawaiian lava flows have shown distinct properties which could be related to the geological structure.

Geopiezomagnetism

ESL's studies in geopiezomagnetics, or geological magnetism, encompass problems relating to the distribution and recent changes of the earth's crustal magnetic material. Applications of such studies vary in the extreme range from sensing geological stresses preceding earthquakes to the discovery of moon-surface lava caves for astronaut housing.

By taking advantage of a lowering of the water level of the lake—Franklin D. Roosevelt Lake—behind Grand Coulee Dam in Washington, ESL scientists are investigating the magnetic effect of a known stress by a nonmagnetic load on the geological structure. This particular investigation may establish the boundaries on the magnitude of the piezomagnetic effects detectable in the field with presently available instrumentation. After a reconnaissance trip in 1968, the investigation began with a second field expedition in 1969. During this latter expedition, 36 fixed observation points were established at varying distances as far as 10 kilometers from Roosevelt Lake. Magnetic observations were made at each of these points while the Lake was at its highest level. During a third trip, also in 1969, the stations were reoccupied while the Lake was at its lowest level. Plans are underway for reoccupation of these stations during the summer of 1970 when the Lake is again full.

SEISMOLOGY

Service Programs

ESSA, through its C&GS component, operates and maintains a network of 20 seismological observatories in the United States and its possessions, and assists in the operation and maintenance of a network of 16 cooperative seismological stations that are under the guidance of universities, research institutes, or other Government agencies. These seismological facilities furnish basic data on earthquakes occurring throughout the world, and are particularly important for the data provided on U.S. earthquakes that have a direct effect on lives and property.

Data are obtained from specialized instruments which monitor and record vibrations in the earth caused by earthquakes and large manmade disturbances. By analyzing these seismic traces (seismograms), seismologists are able to detect, identify, and locate earthquakes; determine earthquake magnitudes; better understand the nature of the earth's crust, mantle, and core; and map seismic risk areas accurately. Similar data for many parts of the world obtained through exchanges with other nations are utilized to support the above analyses.

Engineering Seismology

Engineering seismology in the Office of Seismology and Geomagnetism of the C&GS involves the study of earthquake occurrences and their effects on manmade works. Activities in this field provide the engineer and the construction industry with essential information—description of ground and building motions resulting from earthquakes—for the design of the earthquake-resistant structures.

In regions of strong earthquake activity, specially constructed seismographs are placed within a wide variety of structures and upon various types of soil and rock formations to record earthquake motions. These instruments, inoperative until triggered by an earthquake, record the acceleration, velocity, and displacement caused by earthquake-induced motions at the site. Through broad geographic and geologic spacing of these seismographs, a wide range of response to motions is determined from different types of soil and geologic foundation materials; of couplings between the foundation and structures; and of the earth's structures themselves when subjected to a spectrum of earthquake vibration.

Earthquake data are being used by the C&GS to produce seismic probability maps which aid local officials in the formulation of their building codes and assist architects and engineers in the design of earthquake-resistant structures.

Damage resulting from landslide caused by a severe earthquake.

At the end of the reporting period, the C&GS maintained 341 strong-motion seismographs in nine States and eight instruments in each of eight Central and South American countries. Approximately 100 of these instruments are owned by ESSA; the rest are owned privately and maintained cooperatively. An additional 368 seismoscopes which measure only the maximum acceleration are installed and maintained in west coast locations by the C&GS Seismological Field Survey in San Francisco, Calif.

Earthquake Investigations

ESSA, through the Seismology Division of the C&GS's Office of Seismology and Geomagnetism, serves as the global compilation center for a worldwide service program through which 300 countries and territories submit telegraphic and airmailed reports of earthquakes recorded at their observatories. Data from these reports are fed into a high-speed computer from which earthquake hypocenter determinations are returned. The hypocenters provide basic data for seismic reports; such reports are being sent experimentally over international meteorological telecommunication circuits to improve their timeliness.

Since 1961, data from over 35,000 computed hypocenters are on punched cards at ESSA. Such cards provide answers to requests for information and data for automatic plotting of seismic histories. Since 1968, the Environmental Data Service (EDS) component of ESSA has assisted the C&GS by distributing these cards to subscribers.

The National Earthquake Information Center (NEIC), located in Rockville, Md., was established in 1966 to disseminate seismic information to technical and public users. The NEIC has located over 150 large magnitude earthquakes within 2 hours of their occurrence, providing a fast service useful as guidance for aftershock studies and disaster relief efforts.

Pacific Tsunami Warning System

The Pacific Tsunami Warning System operated by ESSA's C&GS provides warnings of the approach of a tsunami (seismic sea wave) to inhabitants living anywhere within the Pacific Basin. The National Tsunami Warning Center, the control center for the Pacific Tsunami Warning System, is also operated by the C&GS and is located at Honolulu, Hawaii. Data are collected and warnings disseminated through cooperative arrangements with countries and territories bordering the Pacific Ocean.

The first indication of the possible generation of a tsunami is the recording of an underwater or coastal earthquake by one of 20 cooperating seismograph stations (eight of these seismograph stations are operated by C&GS personnel; the remaining 12 stations are operated by cooperating institutions and foreign Governments) located within the Pacific Ocean Basin; an alert is then flashed to the Honolulu Control Center. After the Honolulu Control Center determines that a possible tsunami-generating earthquake has occurred, tide stations are alerted to report the occurrence of actual waves; those tide stations nearest the earthquake epicenter provide the first confirmation. Upon confirmation of a tsunami, a warning is issued by the Honolulu Control Center to all countries and territories participating in the Pacific Tsunami Warning System.

Communications are accomplished through the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD) facilities to avoid duplication of effort. Civil Defense, local law enforcement agencies, and military units disseminate warnings to the American public. Participating agencies of other countries are responsible for arranging communications between their agency and the nearest U.S. communications facility and for providing dissemination to their local population.

In addition to the National Tsunami Warning Center at Honolulu, the C&GS operates a Regional and two local warning systems in Alaska. The Regional Tsunami Warning System in that State is located at the Palmer Observatory, and the local systems are at the Adak and Sitka Observatories. Local facilities are responsible for issuing warnings to the public of nearby tsunamis. The Palmer Regional Center issues warnings to the entire State on all tsunamis threatening the Alaskan coast. These warnings are issued after prompt analyses are made of the seismic data recorded at the Palmer Observatory and its two satellite stations, together with seismic and tide data telemetered to the Palmer Regional Center from four seismological observatories and eight tide stations in the State.

A regional system was under development in the State of Hawaii during the reporting period; it will become operational in mid-1970. This new experimental warning system for locally generated tsunamis will consist of five seismic stations (one on the Island of Maui and four on the Island of Hawaii) and two hydraulic stations (on the Island of Hawaii) to record any possible tsunamis. Data from these stations will be telemetered by radio to the Honolulu Observatory for rapid analyses and early warnings to threatened coastal regions of the State. Additionally, ESSA operates the World Data Center for Tsunamis.

Research and Development Programs

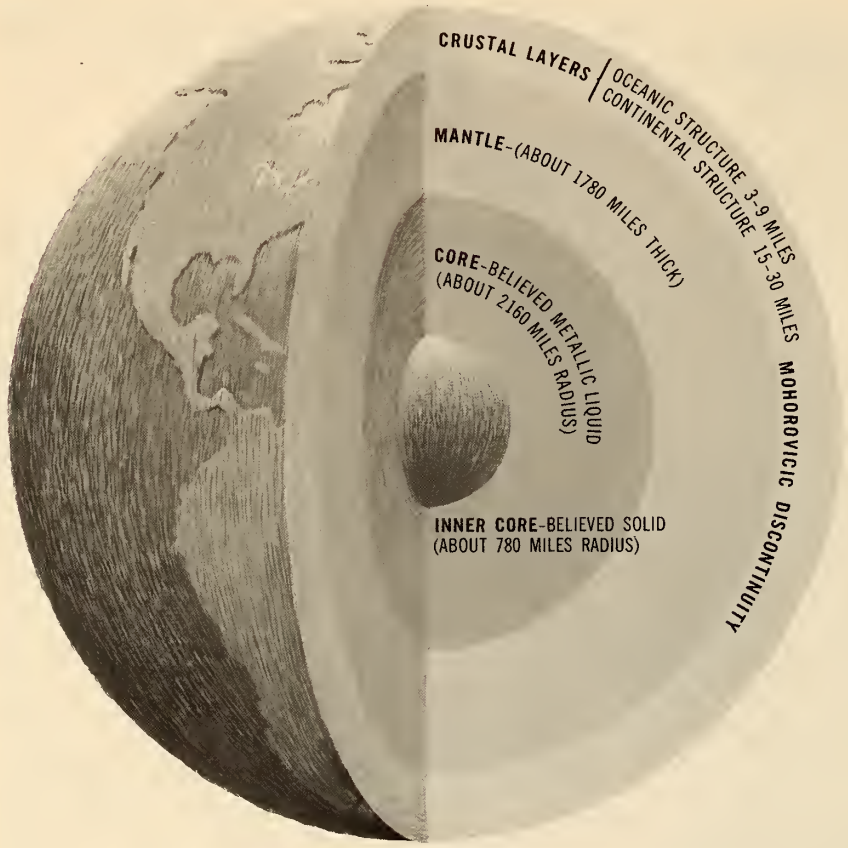
The R&D programs in seismology within the C&GS are concentrated in the Seismology Division and the Geophysics Research Group, and are directed toward improved understanding of the natural forces generating earthquakes, of the mechanics of earthquakes, and of ways to quantify the earthquake hazard potential in given regions. Information derived from these studies has direct application to the ultimate development of a prediction system for earthquakes and tsunamis and to the design and engineering of earthquake-resistant structures.

Withing the RL, the bulk of the seismological effort is concentrated in the Earth Sciences Laboratories (ESL), with most of the seismic research in ESL's Earthquake Mechanism Laboratory (EML). The ESL's seismology research program involves: (1) detection of movements and monitoring of geophysical parameters along active faults; (2) special area studies; (3) investigation of the effects of earthquakes; (4) interpretive and analytical studies related to earthquake mechanisms; and (5) studies of the propagation of seismic energy through the earth and the relation of propagation characteristics to global tectonics.

Earth Structure and Earthquake Mechanisms

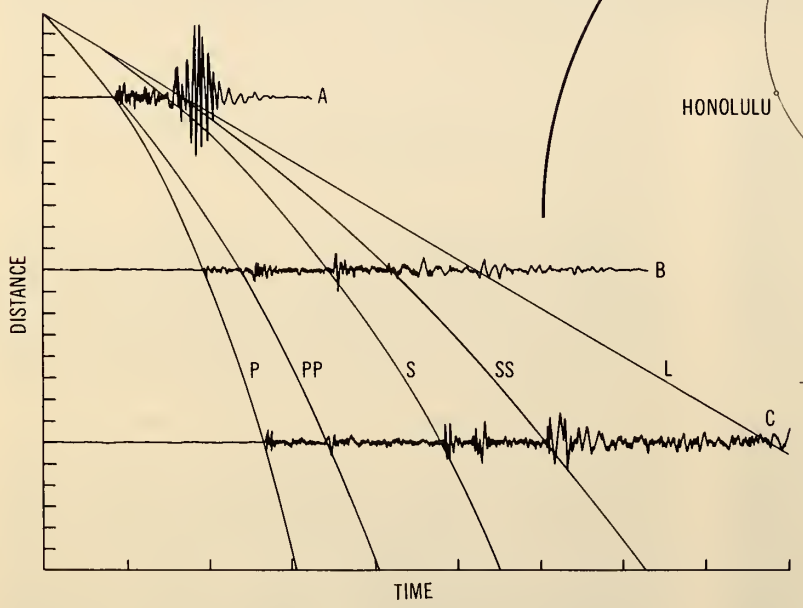
Research which extends and clarifies knowledge on the physical structure of the earth and the physical mechanisms of earthquakes is aimed at acquiring basic information for possible use in earthquake prediction. Instruments are deployed in locations of known seismic activity to monitor all geophysical phenomena at the site. Analyses of the seismic data received at these sites reveal correlations between the earth's physical or dynamical properties and the accumulation and release of elastic strains associated with earthquake occurrences. Such correlations might enable seismologists to establish premonitory phenomena which could give warnings of impending, potentially destructive earthquakes.

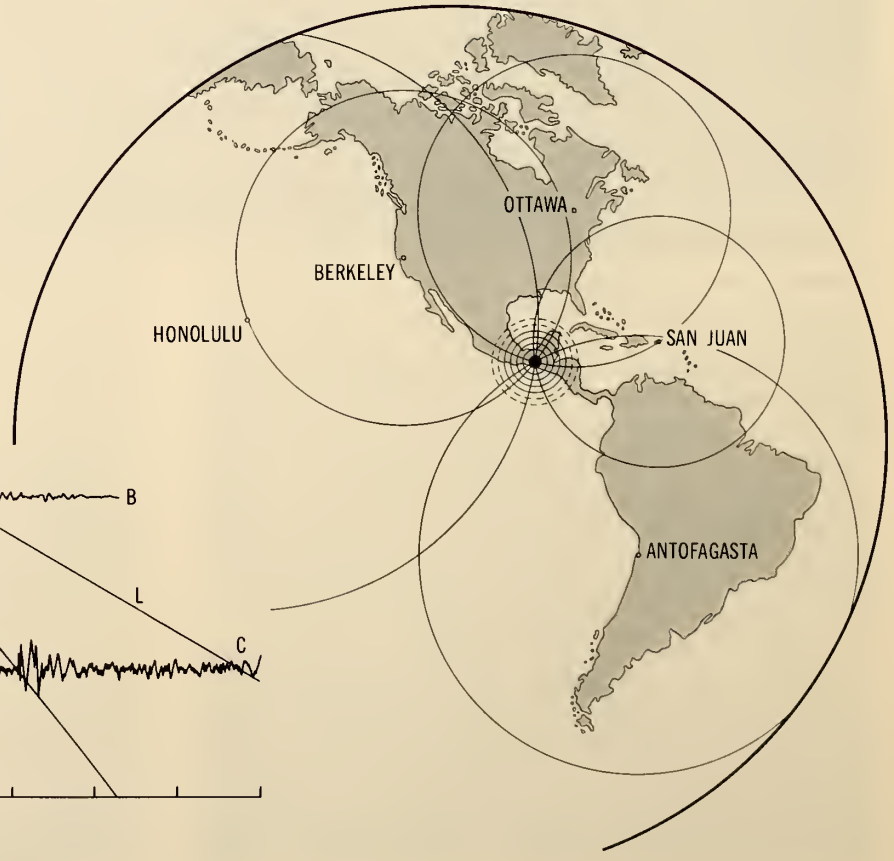
Significant information about earthquakes and their processes is obtained by analyzing seismic waves recorded at C&GS and cooperative seismological observatories. Data obtained are used to determine the geographical locations of earthquakes, their focal depths, their magnitudes, their energy propagation patterns, and details of the earthquake process itself. Seismic waves provide a major source of information about the structure and composition of the earth's interior, furnishing valuable data to other geophysical disciplines. Research studies involve the development and use of local, regional, and teleseismic tables, and their automatic data processing application. These studies are fundamental to geophysics because of their contributions to knowledge on the internal constitution of the earth and



Seismologist's concept of the interior structure of the earth.

Graphical method for locating earthquakes involving the determination of distance from seismograph station to the earthquake source.





its present dynamics; such studies are also important to the fields of engineering seismology and tsunami generation. Efforts are being made to increase the value of the seismic wave records by improving recording instrumentation, by increasing earthquake location determination accuracy, and by developing more advanced data processing capabilities to include larger quantities of data in the analysis.

The University of California Seismographic Station at Berkeley and the EML have cooperated in an experiment to record seismic waves along a profile from the east slope of the Sierra Nevadas to San Francisco Bay, using as energy sources the BOXCAR and BENHAM events—high-yield nuclear explosions detonated under Pahute Mesa in Nevada. A line of stations was established along the azimuth from the east slope source area in eastern California at Mammoth Ski Lodge to San Francisco Bay and beyond to the Lamont-Doherty Geological Observatory's Ocean Bottom Station off Point Arena, Calif.

An essential element in analysis and interpretation of seismic signals is knowledge of the geology and seismic background characterictics of both the areas of seismic activity (natural and manmade) and the areas where detection instruments are located. The portable seismic instruments developed by the EML as part of its Data Acquisition and Analysis (DACAN) System provide the means by which the needed information can be obtained.

A large seismic array in Norway is expected to enhance greatly the capability of seismologists to detect and identify small seismic events. During FY 69, important preliminary tests and calibrations were performed on the new array by EML research groups. The EML developed and built six systems to make its DACAN units compatible with the Large Aperture Seismic Array (LASA) sensors, and tested these systems at the LASA-Montana facility near Billings, Mont. Personnel from EML accompanied the five DACAN portable seismic recording systems to Norway for field experiments. The field experiments attempted to answer whether a noticeable amount of seismic information was gained by recording at the bottom of the 60-meter wells at the Norway site, and to determine at what distance from the sensors did microseisms become incoherent at the site. Specific field tests were made to determine amplifier (LASA and DACAN) and seismometer frequency response and gain, and amplifier data-line tape recorder system noise. Other field recordings of particular interest were earth-noise at 7-hour intervals, earthquakes heard on an audiomonitor, and cultural noise heard on an audiomonitor. Selected portions of the field data recorded in analog form have been converted to digital form. Some preliminary analysis was done in time to supplement the work in the field by using the Sandia Corporation computer facilities at Livermore, Calif. The field experiment has been completed and data analysis is in progress.

Field operations on a reimbursable project were conducted in the Northern Territory of Australia during the summer of 1967. The objectives of the overseas operations were to describe the parameters of recorded microseisms and the seismic signal reception. Seismic noise recorded in Australia is 5 to 20 decibels higher (at 1 Hertz) than at a Vernal, Utah, site. The detection threshold of seismic events in the Northern Territory of Australia is slightly higher than in Utah for shallow events. The amplitude of microseismic activity shows a correlation with meteorological activity. Many shallow seismic events recorded displayed anomalously short periods.

At present, most hypocenter determinations are accurate to within 25 kilometers of the true position, while a few are only accurate to within 50 to 100 kilometers. When assigning zones of seismic risk to a region, knowledge of which faults in a complicated system are active is important. Most faults are buried, and usually earthquakes leave no surface evidence. Consequently, the only way to identify active faults is to locate epicenters accurately. Identification of active faults will improve the accuracy of risk zoning, eliminate uncertainties, and increase public confidence.

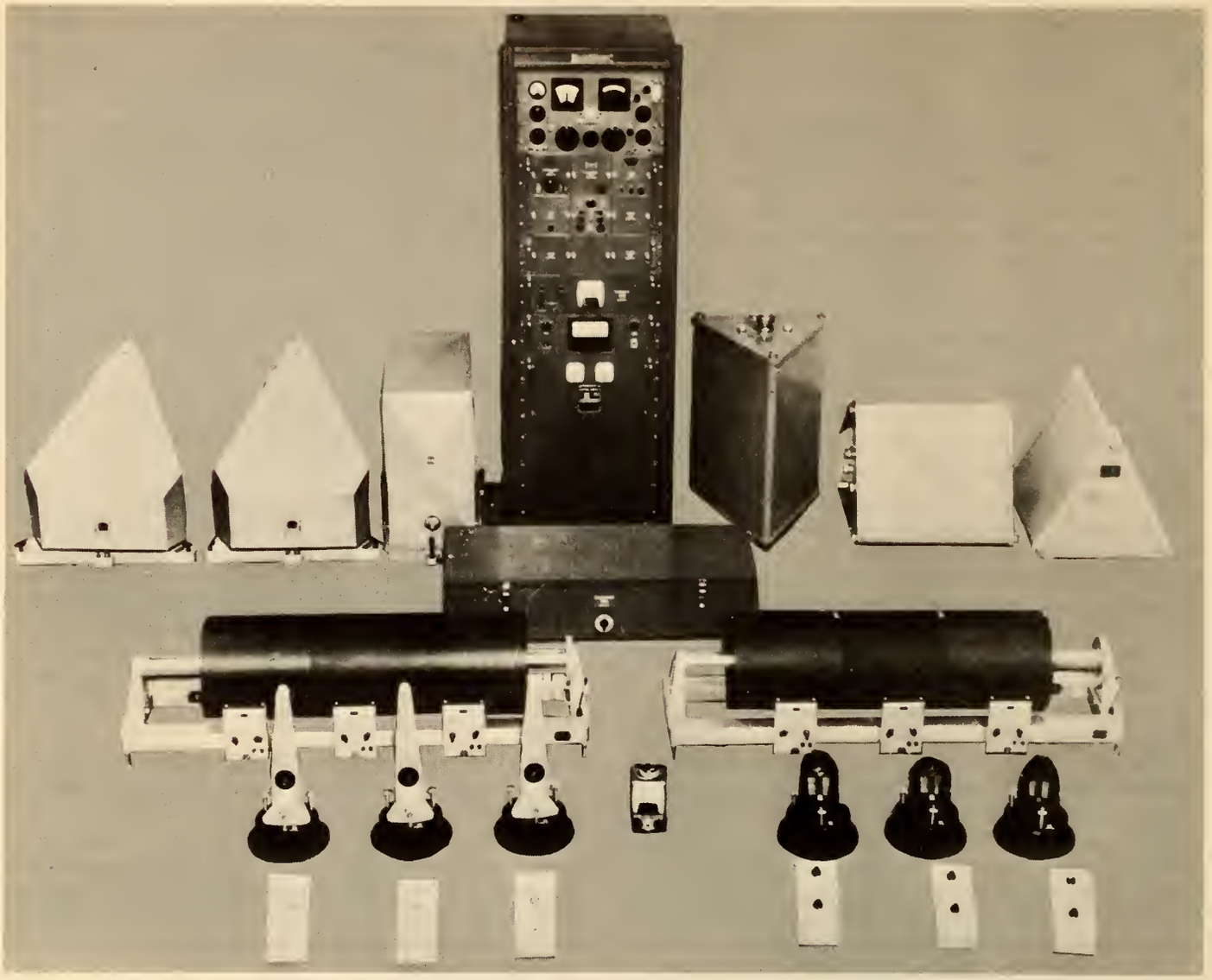
Tsunamis are generated by shallow focus earthquakes that occur at certain positions with respect to the sea floor. Shocks with deep foci or those that occur inland do not cause tsunamis. Some of the regions where the most disastrous tsunamis have originated are the very regions where location accuracy is the worst; for example, in the Aleutian Islands and along the western coast of South America. Improved location accuracy will reduce the false-alarm rate of the Pacific Tsunami Warning System and lower its cost, but more importantly will increase public confidence in the System.

The C&GS investigated methods for incorporating local and regional source and station corrections into standard travel times to increase the accuracy of hypocenters. This effort is complicated by highly complex regional crustal and upper mantle anomalies and by lateral inhomogeneities in the lower mantle. A detailed study of *P*- and *S*-travel times and station corrections for Japanese earthquakes was completed, and travel times for multiply-reflected core waves were also computed.

More sophisticated methods for locating earthquakes were investigated by the C&GS. The objective was to eliminate automatically those spurious readings which fall outside the expected region of error. This work was done in cooperation with the International Seismological Centre in Edinburgh, Scotland, and has resulted in programs which produce accurate locations with little human attendance.

ESSA scientists worked with personnel from the Lamont-Doherty Geological Observatory on studies of earthquake epicenters and mechanisms, using data obtained from the Worldwide Network of Standard Seismograph Stations. From these data, they were able to develop a new comprehensive global tectonics model and to determine its relation to sea-floor spreading and continental drift.

Two ESL studies pertinent to earthquake mechanism solutions neared completion during FY 69. In the first study, solutions for deep- and intermediate-depth earthquakes were investigated on a worldwide basis in an attempt to study the distribution of stress within descending plates of lithosphere as postulated in the new global tectonics. The results support the hypothesis that plates of lithosphere sink into



Seismograph instrument stations used in Worldwide Network of Standard Seismograph Stations.

the asthenosphere as a result of body forces on excess mass within the plates and "hit bottom" beneath the asthenosphere. In the second study, focal mechanism solutions were obtained in a regional study of western South America. These included the largest earthquakes that occurred during the 7-year interval—1962-68.

Research activities are also being directed toward the following: First, development of data processing techniques, including new theoretical considerations and more sophisticated mathematical methods, for use in locating earthquake hypocenters is underway. Studies in travel times of seismic waves and their relation to earth structures, using advanced wave theory, are being made. Second, investigations of new *P*-surface-focus travel times to derive a velocity model of the earth are in process. Third, interpretation of seismological data from networks of stations, located in Nevada and the Aleutian Islands of Alaska, which monitor regional seismicity and seismic effects of nuclear explosions is continuing. These data are expected to extend knowledge of earthquake mechanism, earthquake prediction, and relationship of earthquakes to regional structure.

Strain and Creep Measurements

The ESL conduct basic research designed to improve understanding of the physics of earthquakes. A specific laboratory of the ESL—the Earthquake Mechanism Laboratory, located in San Francisco—investigates seismic events.

During the reporting period, the EML intensified its strain and creep measurements along the San Andreas Fault of California, the principal observational site for earthquake research. Cooperative research work with Stanford University in FY 68 uncovered nearly a dozen examples of magnetic signals preceding creep events on the San Andreas Fault. Steps were taken to monitor both the telluric current and magnetic fields.

Piezomagnetic effects associated with the San Andreas Fault are being studied. Stanford University supported by an ESL grant operates an array of optically pumped Rubidium vapor magnetometers to observe the possible magnetic effects from tetonic stresses associated with earthquakes and creep events. Investigations show that some creep events are preceded by magnetic precursors. Limited laboratory experiments at Stanford and elsewhere have shown that the electrical resistivity of rocks is also stress-dependent.

The objective of ESL in monitoring geophysical phenomena on fault zones is to measure, continually or periodically with the greatest possible sensitivity, all possible indicators which might foretell an earthquake. This objective represents an empirical approach in the absence of confirmed theories for the mechanism of earthquakes. A variety of techniques are being employed in fault monitoring. The EML has established an important geophysical monitoring facility at Stone Canyon near Hollister, Calif. Creep-measuring stations have been established at approximately 30 points along the San Andreas Fault. Fourteen places along the San Andreas and other Faults in California are equipped with 25 Invar-rod creepmeter units.

Even though the installation of creepmeters is only partially complete, some worthwhile data have already been obtained. Analysis of these data has delineated the occurrence of fault creep on the San Andreas, Hayward, and Calaveras Faults. Preliminary analysis of the measurements shows that the time character of fault creep varies considerably from one site to another, even at sites within tens of kilometers of one another and on the same fault. The creep appears to be eventful at some places, and continuous at others. Creep events measured at two sites on the San Andreas Fault suggest a rate of creep propagation on the order of 10 kilometers per day.

Another aspect of the long-range fault creep monitoring program involves the periodic measurement of a series of survey lines. These resurveys detect movement in the immediate vicinity of the faults. Creep survey-line sites were established along the Hayward Fault in Oakland, Hayward, and Fremont, Calif. The EML completed the configuration and design of a new Telemetering Seismometer System field terminal, making the first installation near Watsonville, Calif.

Cooperative work with the Colorado School of Mines revealed evidence of extremely large strain rates near the Rocky Mountain Arsenal's deep disposal well near Denver, Colo. These rates were studied to find their time relationship to damaging earthquakes.

In a cooperative project involving RL's EML, the C&GS, and Colorado School of Mines, two quartz-bar strainmeters were entrenched north of Beatty, Nev., to observe the BENHAM underground nuclear event of December 19, 1968. These instruments, oriented approximately radially to the source, were located at distances of 28 and 71 kilometers from ground zero. A most significant observation was that the strain step from the BENHAM event apparently decayed to near zero within one-half of an hour, whereas earthquake steps do not decay within several days, if at all. This decay with time appeared to be a reflection of the pressure history of the cavity.

To increase the effectiveness of information flow, the EML was connected to a timesharing computer service in FY 68. This computer service is a multiplex-telemetering system designed to carry six channels of strain, creep, or tilt data over one telemetry channel in time sequence. At the San Francisco receving end, the system separates each channel into its proper visual display for recording.

Engineering Seismology

The aim of the C&GS's R&D program in engineering seismology is to reduce loss of life and property resulting from earthquakes by developing information for regional, urban, industrial, and land use planning, by providing earthquake-motion criteria for the design of earthquake-resistant structures, and by supplying data to Federal, State, and local governmental agencies concerned with relieving the impact of natural disasters.

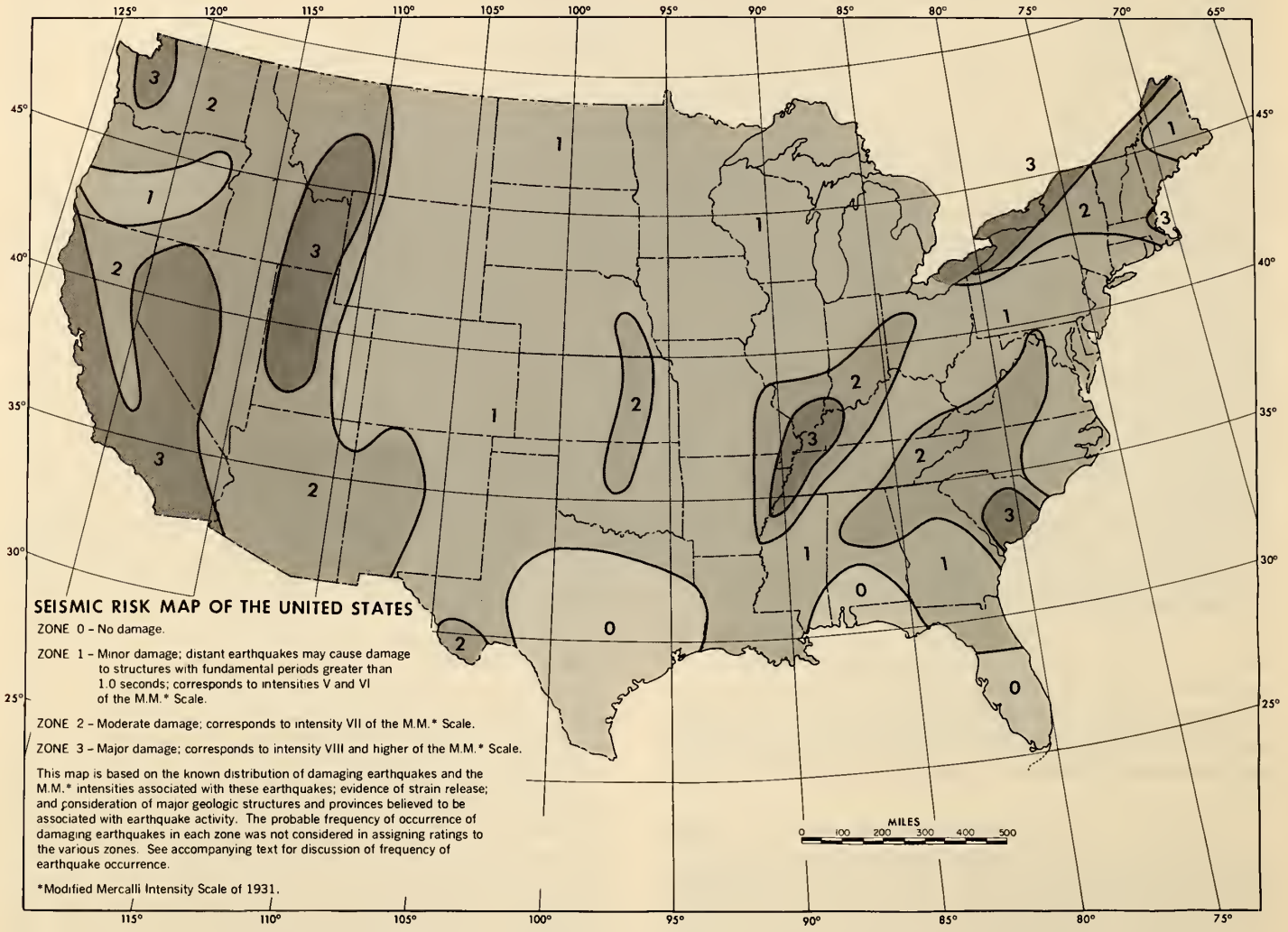
Research in engineering seismology has been planned in conjunction with operational programs in seismology to maximize scientific output from the operational programs. Anticipated benefits of these research efforts are: (1) seismic risk maps to permit the most efficient use of available land consistent with the seismic hazard; and (2) improvement of engineering design principles for earthquake-resistant structures, based upon research studies of the nature of earthquake strong motion.

In keeping with these aforementioned goals, the C&GS conducted a study to develop criteria helpful for evaluating earthquake hazards and to present the results in a form useful for seismic design of building structures. The Geophysics Research Group of the C&GS prepared and issued a seismic risk map, taking into consideration the geographic locations of earthquakes, geological and soil conditions, population densities, and construction types. This map has been accepted for use in the 1970 edition of the *Uniform Building Code*. During FY 69, the Group also modeled the economic losses resulting from earthquake damage to single-family dwellings in California for a maximum credible earthquake and for all earthquakes in California during the past 157 years. For this study, a construction-type sampling survey was made; census data and construction reports provided numbers of units, and structural engineering experts determined housing element failures. Theoretical isoseismal maps were constructed for each event, assigning damage intensities to unitized geographical areas; losses for each geographic area were then calculated and summed.

The C&GS, in cooperation with the California Institute of Technology, digitized strong-motion seismograms and compiled a data bank of seismograms for engineering studies. Amplitude spectra of these digitized events were calculated to obtain relative ground motion, a factor related to soil and geological conditions; in an engineering context, ground motion becomes important in soil-structure interaction.

Inputs into this R&D program include intensity data from damage surveys following destructive earthquakes and strong-motion data from instrumental recordings of earthquake-induced motions on various types of surface geology. The data obtained are analyzed to evaluate the relationship between recorded motion and structure damage, the influence of surface geology upon earthquake-induced motions, the stability of foundation materials during earthquakes, and the variety in response of design structures to earthquake-induced motions. Such information is utilized by the C&GS to compile seismic risk maps which enable Federal, State, and local authorities to formulate policies for building codes and to institute studies for regional, urban, industrial, and land use planning.

Additionally, staff members of ESL's EML have served as consultants with or speakers to such local California groups as: The Office of Emergency Planning Regional Preparedness Committee, developing emergency plans to be put into effect in the event of a major earthquake in that State; the Society of Real Estate Appraisers; the Coordinating Committee for East Bay Fault Slippage in Hayward; a meeting of representatives from engineering-geology firms in the San Francisco Bay area; and the Governmental Services Committee of the City of San Francisco, concerning a proposed parapet hazard abatement law.



Seismic risk map of the conterminous United States showing four zones of no damage, minor damage, moderate damage, and major damage.

Tsunami Generation

Research on the processes by which an underwater earthquake generates a tsunami is underway. Techniques are being developed and instruments improved for measuring and detecting tsunamis in the open ocean; improved forecasts of tsunami travel times and wave heights onshore will provide advanced, reliable warnings on the severity of the hazard.

Research by the C&GS's Geophysics Research Group into the mechanism of tsunami generation involves correlations of earthquake mechanism, water depth, and ocean bottom topography. The objective of the tsunami-supporting research studies is the development of a technique to identify and interpret, immediately following an earthquake, those source parameters of the earthquake that can be related to the generation of tsunamis. Use of seismic phenomena to identify tsunami-generating earthquakes would permit much earlier warnings and would greatly reduce the potential for loss of life and property. Studies were made by the Geophysics Research Group which suggest that tsunami-generating earthquakes may be multiple-shock events, indicating successive ruptures over a long zone. Research is underway to determine whether this study result is a valid criterion for use in efforts to discriminate earthquakes which produce tsunamis.

In another approach to the problem of finding a method for identifying tsunami-generating earthquakes, the Group developed a computer program combining *P*- and *S*-wave focal mechanism solutions. This computer program will be used to study the relationship in orientation of focal mechanism to the generation of tsunamis.

One of the basic research programs on tsunamis is conducted by the Pacific Oceanographic Laboratories (POL) of RL and is designed to increase understanding of the generation, propagation, and onshore runup mechanisms of tsunamis to improve the operation of the Pacific Tsunami Warning System.

During the reporting period, a cooperative research program of the POL and the University of Hawaii was underway; progress has been made on developing several types of deep sea tsunami gages, both free-fall and cable-connected. Six deep sea free-fall wave measurement systems have been completed and shipped to Amchitka Island for use in an experiment in the Aleutian Islands of Alaska. The design is complete and components are being life-tested for a permanent tsunami-measuring system which will be placed on the sea bottom under a North Pacific weather ship. Computer programming was also done in connection with various studies, including hydrodynamic modeling of estuaries, numerical calculation of directional spectra of wave refraction, computation of propagation of free and edge waves, identification of earth regions based on seismic spectra, and spectral analysis of time series containing gaps. Travel time charts, obtained by computer, have been produced for the Pacific Tsunami Warning System.

Significant advances are being made at the University of Hawaii in instrumentation for measuring and detecting tsunamis in the open ocean. Development of accurate tsunami travel time tables for the open ocean and shallow water situations, involving different ocean bottom topography, is underway. This information will result in more accurate and rapid forecasting of tsunami generation, improved advanced warning of its potential destructive power, and better planning by local authorities for the construction of dikes, jetties, and other nearshore facilities as a means to reduce loss of life and property in coastal regions subject to destructive tsunami occurrences.

CARTOGRAPHY

Service Programs

ESSA has the responsibility for the production and maintenance of up-to-date aeronautical charts and related information required for all types of aviation within the United States and for U.S. civil aviation in foreign air space where navigational information needs are not otherwise provided. The requirements for products to meet civil aviation needs and those essential to the management of the National Airspace System are prescribed by the Federal Aviation Administration (FAA). Specifications for aeronautical charts, designed to provide timely and accurate information to both civil and military users with minimum duplication of production, are developed jointly through an interagency agreement between the Departments of Defense (DOD), Transportation (DOT), and Commerce (DOC). Aeronautical charts are the primary media through which rules and regulations pertaining to the National Airspace System are made available to the aviation community.

Visual Charting

Visual Charts are used by pilots engaged in contact flight under Visual Flight Rules (VFR). These Charts graphically portray topographic and cultural detail—such as drainage, roads, railroads, and other distinguishing landmarks—for terrain reference. ESSA's C&GS prepares four different types of Visual Charts, issuing revisions at intervals ranging from 16 weeks to 1 year. Included in the four series of VFL-related products are: Locals at 1:250,000 scale of high-density terminal areas; Sectionals at 1:500,000 scale for slower speed aircraft; World Aeronautical Charts at 1:1,000,000 scale for higher speed aircraft; and a smaller scale Wall Planning Charts.

Instrument Charting

Instrument Charts contain airways, radio facilities, and other complex information pertaining to the National Airspace System for those flying under the Instrument Flight Rules (IFR). Included among the Charts of this series are: Enroute High and Low Altitude Charts to assist pilots in enroute navigation; Instrument Approach Procedure Charts to provide information on instrument approaches to airports, with approved procedures; and Standard In-

strument Departure (SID) Charts—the newest series—to show preferred routing from takeoff to enroute fixes and to reduce air traffic control clearance communications.

To meet the prescribed format and time schedule for the SID series, cartographic activities for the series within the C&GS were expanded during FY 69. This new series was funded during FY 69 by FAA, with the publication schedule providing one SID Chart every 8 weeks. These SIDs will be produced in bound volumes, one for the Eastern and one for the Western United States, replacing 31 charts that formerly covered the conterminous States; a third volume will be produced for Alaska.

Other IFR-related products include: Controller Charts to provide FAA personnel at Air Traffic Control Centers with a graphic display of all current and pertinent data necessary to manage their responsible portion of the National Airspace System; Central Airspace Reservation Facility (CARF) Charts to permit FAA personnel to coordinate military and important civil air traffic with Air Traffic Control Centers; and Airport Obstruction Charts to show pilots obstruction locations, heights off runway ends, precise airport elevations, runway lengths, and other data required for safe maximum aircraft loading. Aircraft Position Charts are designed to meet unique information requirements of long-range international flights.

Research and Development Programs

The tremendous growth in the Nation's aviation during the past 30 years has caused an increasingly crowded airspace problem which at present requires a total reevaluation of the National Airspace System and the means for graphically describing it. Although aeronautical charting has fulfilled the aviator's informational needs during these past 30 years, time is no longer available within present resources to make in-depth studies on terrain depiction techniques, to evaluate graphic arts processes, or to provide color composition possibilities for meeting the urgent problem of describing the National Airspace System graphically. Valuable knowledge gained from previous research studies was partly applied to existing charts and will be employed in information portrayal solutions to meet new charting requirements. Past research on color-process printing made possible the elimination of one five-color press run for each Visual Chart produced.

Although simulated-process printing has been successful in reproducing tints, the selection of "primary colors" to satisfy the solid line work represents an important breakthrough in meeting the specifications for navigational charts. This simulated-process printing method requires the manufacture of precise interposing film screens and the development of a special color chart.

Computer-Assisted Cartography

During the past 2 years, significant progress was made toward the goal of increased use of automation in chart production. The technical feasibility of the computer-assisted cartographic data-handling system and the ability to accomplish on-line updating of certain important aeronautical charting programs were demonstrated.

A major obstable to automation of the cartographic process was overcome by the unique characteristic of the systems concept that now permits the cartographer to "get at" the computer-stored data base, to manipulate and work on these data, and to arrange them to satisfy the requirements of the cartographic product. This characteristic is absolutely essential if full automation is to be a practical cartographic tool.

To determine whether automation could be accomplished and whether full-scale implementation was justified, a detailed systems design was developed and its soundness proven in an operational environment. The C&GS let a contract in June 1968 to implement a pilot system for a selected series of cartographic products covering a limited geographic area. The Alaska Enroute Low Altitude Charts and the Alaska Instrument Approach Procedure Charts were selected for the initial test. The pilot system procedure involved the establishment of a parallel production operation in conjunction with the present manual operation; this procedure provided training for C&GS cartographic personnel and permitted evaluation and systems design evolution of the system.

Frequent revision schedules and the increasing tendency to relate publication cycles to the National Airspace Amendment Day, which occurs every 28 days, make automation of aeronautical charts a challenging cartographic problem. Revisions to the Instrument Approach Procedure Charts are published weekly, the entire Enroute High and Low Altitude Chart series is produced every 4 weeks, and the Visual Charts are available on a 6-months' schedule coincident with the effective date of an airspace amendment.

The principal constraints on meeting the increasing demands for timely information of air-cartographic materials rest upon the annual methods of cartographic revision and production and upon the shortage of skilled cartographers. Developing new systems to permit shorter response time and to reduce the cost of production are urgently needed.

MARINE GEOPHYSICS

Research and Development Programs

Marine geophysics is of continuing and increasing importance as the need grows for more accurate descriptions of the land-sea boundary for geodetic, geomagnetic, and seismological investigations. This subject is discussed within this chapter rather than in Marine Description, Mapping, and Charting because the techniques and methods relate to the solid earth phenomena, although the measurements are largely made from water-based platforms.

The growing economic importance of marine geophysics has generated new requirements for marine geodetic and geomagnetic data because of the potential commercial development of the Continental Shelf.

Research programs in marine geophysics embrace the disciplines of geodesy, geomagnetism, and seismology and largely involve the land-sea interface.

The focus of ESSA's marine geophysics program during the reporting period was directed toward suboceanic structure investigations, geotectonics, sedimentology, and ocean basin characteristics. Research was conducted by both the Atlantic Oceanographic Laboratories (AOL) and the Pacific Oceanographic Laboratories (POL) of RL to gain a clearer understanding of the structure, nature, and evolution of the ocean basins and the continent-ocean basin boundary. Major research efforts centered on the study of island arcs and associated deep sea trenches because tectonic forces in the early phase of their evolutionary cycle are still active in those geomarine areas. Research of both Oceanographic Laboratories was accomplished through analysis, interpretation, and presentation of gravity, magnetic, and seismic data from a systematic acquisition program.

Suboceanic Structure Investigations

A number of studies and investigations were conducted by the Oceanographic Laboratories during the past 2 years as part of the international program to investigate the earth's upper mantle. Investigators from POL completed and published a marine geophysical study of an area of 120,000 square miles off the coast of California and concluded an investigation of an island arc structure in Indonesia in FY 68. A study of the earth's crust underlying the North Pacific using magnetic characteristics of the crust was conducted; structural interpretations for the Pacific Basin north of Alaska based on gravity observations were also made. A continuous geophysical profile (bathymetry and magnetics) across the South Pacific at latitude 35° S. was undertaken and completed, and the results were published. This profile revealed numerous submarine volcanoes, reported the existence of a new submerged mountain range, and located another previously known mountain system with more accuracy.

Scientists of POL discovered two Fracture Zones—Amlia and Adak—normal to the Aleutian Trench with offsets of 50 kilometers and a major deep sea Channel—Seamap—in the Aleutian Abyssal Plain during FY 68. This deep sea Channel is a geologic feature of the Northeast Pacific predating the subsidence of the Aleutian Trench. The significance of this Channel to studies of Pacific Ocean tectonics is considerable, for its existence has provoked new thought on the pattern of sediment deposition in the Northeast Pacific. Also, POL scientists discovered a westward extension of the Murray Fracture Zone; the former hypothesis that the Zone trended into the Marcus-Necker Ridge is now questionable. Results of the magnetic characteristics associated with the Amlia and Adak Fracture Zones, and studies of the characteristics of the westward extension of the Murray Fracture Zone and of the Seamap Channel were published in FY 69.

Final reports on the morphology of an area north of the Hawaiian Ridge and the general bathymetric setting and gravity anomaly of Cobb Seamount, and initial reports on the gravity of the Aleutian Trench were presented in FY 69 by POL. Field work was conducted in support of the continuing study of magnetic anomalies and topographic data in the central North Pacific.

Geotectonics

Investigations into geotectonics by AOL involved research directed toward the development of a fundamental understanding of the genesis, tectonics, and geomorphic evolution of the continental margins (shelf and slope) and deep sea floor. These studies emphasized such large-scale problems as continental drift, geological relationship between continents and ocean basins, and origin of ocean basins.

During the past 2 years, various geotectonic field investigations were conducted. Among the completed investigations were studies along the continental margins of Australia and northwestern Africa; an analysis and interpretation of data on sea-floor spreading and continental drift were also concluded. The geomorphology and geological structure of the North African continental margin were delineated to provide additional evidence of sea-floor spreading.

AOL scientists conducted research in other geographic regions on the structural fabric of a number of continental shelf and slope areas; full explanations of these phenomena in terms of continental rift and drift hypotheses were anticipated. An analysis and interpretation of data collected along the east coast margin of South America were also accomplished.

One of the principal efforts during FY 69 has centered on the "jigsaw fit" of the edges of the Australian and Antarctic continents. A computer-evaluated reconstruction of the postulated Australia-Antarctic protocontinent shows a high degree of probability that these two continents were once joined.

Sedimentology

Sedimentological research includes an analysis and interpretation of the source, diagenesis, composition, and transportation of ocean basin sediments. Standard sedimentological and geochemical techniques are applied to samples collected in systematic surveys; these surveys are designed to increase basic knowledge of the processes and geochemistry of the sea floor. Research into the mass physical properties of submarine sediments provides a clearer understanding of the stability of the sea floor, effects of loading and shock, engineering properties—shear strength, density, and porosity—of the sea floor, and the process of lithification.

In FY 68, scientists in both Oceanographic Laboratories completed studies on the distribution of mass physical properties of submarine sediments in the North Atlantic and North Pacific. Measurements of shear strength, bulk density, and pore pressure were completed by AOL investigators

Ocean floor at depth of 537 fathoms (3,222 feet) south of Australia.

off the coast of Massachusetts. Clay mineralogy samples, collected from the Java, Mindanao, and Mariana Trenches, were laboratory-analyzed. A geochemical study of the carbonate (high and low magnesium carbonate and aragonite) and noncarbonate content of samples from the Straits of Florida was also completed.

Studies on the degree of variation in selected mass properties, both geographically and for different types of submarine sediments, were completed in FY 69. With the aid of a submersible, a detailed study of the local (400 square centimeter area) variability of certain mass properties was completed for a deep sea carbonate deposit. Field work was completed on the in-place measurements of shear strength and bulk density. Presently, an investigation is in progress on sedimentary characteristics of the Tobago Trough in the southeastern Caribbean Sea that will define the dynamics and processes involved in the deposition of material in this Trough.

Ocean Basin Characteristics

Studies on ocean basin characteristics focus on improved understanding of the processes determining the structure of sea floors, continental shelves, ocean basins, island arcs, and deep sea trenches, and of those processes involving sedimentary deposition and geomorphology.

During the reporting period, AOL scientists were involved with various investigations describing the sea floor morphology, interpreting the effects of sedimentary and tectonic processes, studying the origins and prominence of morphological features, and predicting morphological changes.

Work continued on the study of the bottom morphology of Chesapeake Bay (15 sheets at a scale of 1:50,000) and on the depositional and erosional history of the lower Potomac River.

Another accomplishment by AOL researchers was the collection and interpretation of data on the continental margin of Brazil; a bathymetric map was completed. In FY 69, researchers prepared a detailed bathymetric study and seismic reflection profiling along the eastern margin of canyons extending from the platform into the Atlantic Basin. An investigation of the Amazon Canyon off the Amazon River sought to delimit and determine the possible origin of the Canyon.

Other studies conducted by AOL have determined the shallow structure of the entire continental margin of Brazil and Uruguay that developed following the postulated separation of South America and Africa by the creation of the South Atlantic Basin. Intensive efforts in the southeastern Caribbean Sea, at the junction between the Lesser Antilles island arc and the South American continent, have placed severe constraints on any postulated lateral movement between the island arc and the continent as predicted by the recent plate tectonics concept.

Additional accomplishments by AOL within marine morphology during FY 69 include a bathmetric map from the Upper Mantle Project area off the coast of California; descriptions and interpretations of two submarine canyons—Cayar and Trou sans Fond—along the Atlantic margin of Africa; a detailed bathymetric map of the Straits of Florida and an accompanying test; and an interpretative report on a related series of submarine canyons off Ceylon.

Global data collected during the world cruise of the USC&GS ship *Oceanographer* in 1967 were processed and analyzed, and a summary report prepared during the reporting period. Scientists at POL completed analyses on several aspects of the geophysical data collected. An investigation of the East Australian Current by the *Oceanographer* in September 1967 resulted in the discovery of a jet in the Current; the existence of a countercurrent beneath the Current was also verified.

Reduction and analysis of data obtained in the study of Bimini Inlet in the Bahamas during 1967 continued; analytical expressions were developed relating bottom geometry, fluid flow, and sediment transport in this Inlet environment.

6 MARINE DESCRIPTION, MAPPING, AND CHARTING

ESSA's programs relating to Marine Description, Mapping, and Charting fall within the fields of marine navigational charting and oceanography. Included in these programs are studies of coastal tides and currents and the interaction of the sea and land along coastlines and estuaries.

The principal service activities of ESSA in descriptive oceanography involve tides, tidal currents, and the hydrography of coastal waters and estuaries. The increased effort in bathymetry (bottom topography) of the Continental Shelf and deep ocean areas is attaining importance as a specific service activity.

The tide program of ESSA consists of the operation by the Coast and Geodetic Survey (C&GS) of approximately 200 permanent or temporary tide gages to monitor tides along the coasts of the United States and its possessions. Data from these gages form a basis for determining the tidal characteristics from which tide predictions are made. The datum planes used as a reference for depths on nautical charts are determined from tidal data.

Tidal current service programs include the systematic collection of current observations and the reduction, analysis, and interpretation of the resulting data. These data are subsequently used in experimental and theoretical studies of estuarine dynamics, in the maintenance of coastal fisheries, and in sedimentation mechanics. Characteristics of tidal currents are described, predicted, and published annually by the C&GS.

The service programs in hydrography are concerned with various operations necessary for the production of nautical charts and related publications required to improve the safety of marine navigation. These programs encompass such activities as hydrographic surveys and mapping, involve investigations of hazards to navigation and locations of aids for the marine navigator, and include *U.S. Coast Pilot* information. A variety of nautical charts is produced by the C&GS as a result of these surveys.

The research and development (R&D) efforts in Marine Description, Mapping, and Charting are the joint responsibility of the C&GS and the Research Laboratories (RL). ESSA's research programs relating to oceanography are concerned with improving knowledge of tidal propagation in both estuaries and the deep ocean, estuarine dynamics, nearshore ocean circulations, bathymetry, deep ocean circulations, wave phenomena, and sea-air interactions. Because marine geodesy, geomagnetism, and seismology are concerned with the solid earth phenomena at the bottom of the sea, these subjects are discussed under Earth Description, Mapping, and Charting.

The C&GS operates a fleet of 15 oceangoing vessels to assist ESSA's service and research efforts for the collection of information along the Continental Shelf and deep ocean basins. These vessels measure the bathymetry of the oceans, the ocean and estuarine currents for navigational purposes, and such geophysical parameters as marine gravity and geomagnetism.

MARINE NAVIGATION, MAPPING, AND CHARTING

Service Programs

The marine navigation, mapping, and charting program involves the production of nautical charts and publications for marine navigation. This program includes hydrographic surveys for large-scale shipping operations, photogrammetric shoreline surveys for coastal operations, and the compilation, reproduction, and distribution of nautical charts, *U.S. Coast Pilots*, and related navigational information. This program element also involves investigations of navigational hazards and locations of aids to the navigator. Objectives of the program are to complete and maintain on a current basis the charting of the coastal waters, including harbors and estuaries of the United States and its possessions.

Nautical Charts

Nautical charts are the principal products of the marine navigation, mapping, and charting program. These charts are basic tools for the safe and efficient conduct of water-

borne commerce and are vital to the rapid expansion of marine industries and recreational boating.

Six types of charts were published by the C&GS during the reporting period. Four types—Sailing, General, Coast, and Harbor Charts—are prepared for general users at varying scales of detail; and two types—Small-Craft and Special-Purpose Charts—are designed for particular user groups.

Mariners plying the oceanic waters find Sailing Charts useful to plot their course between distant coastal ports and on approaches to the coast. They turn to General Charts to fix a position from visual sightings and radar images. Mariners trace their passage on Coast Charts if they intend to navigate nearshore coastal waters, enter large basin harbors, and traverse certain large inland passages. For safe navigation within active harbors and restricted channels and passages, they choose Harbor Charts.

Recreational boaters seeking information on marina locations and facilities, tides and currents, anchorages, the Weather Bureau's (WB) Marine Weather Services, and basic nautical rules look for such material upon Small-Craft Charts. For plying coastal waterways, boaters acquire Special-Purpose Charts such as the Intracoastal Waterway Charts, covering the Atlantic and Gulf Intracoastal Waterway, to locate themselves. This latter series of charts is being converted to the Small-Craft Chart format at the present time.

Ship Operations

Hydrographic surveys are performed to determine water depths and bottom configuration and characteristics, to locate physical obstruction to navigation, and to portray navigation aids for use in producing a graphic description—nautical charts, bathymetric maps, and *Coast Pilot* information—of navigable waters to insure safe passage for the mariner. Near the coast and in protected waters, survey work is done by launches operating from larger vessels or from shore bases. In unprotected waters and in the open ocean, work is performed by survey ships.

Coastal Mapping

Coastal mapping consists of photogrammetric shoreline surveys. These surveys employ photography and office compilation to delineate shorelines, to locate onshore and offshore features, and to establish and extend geodetic control required for hydrographic surveys and for nautical chart compilation and maintenance.

U.S. Coast Pilot Production

The preparation of *Coast Pilots* involves extensive field investigations and office compilation of data collected on the coastal waters of the Nation. The eight-volume *Coast Pilots* series contains a wide variety of navigational information which cannot be adequately presented on nautical charts. This information includes regulations for general and local navigation; descriptions of prominent natural and cultural shoreline features; accounts of channels, anchorages, hazards, and tide and current characteristics; details on pertinent weather conditions for the area; and listings of available port facilities. Two *Coast Pilot* volumes are revised and issued each year; yearly supplements to the remaining six volumes are also prepared.

Research and Development Programs

The R&D program for marine navigation, mapping, and charting increases the accuracy, timeliness, and efficiency of marine chart production. Current efforts are directed toward automation and integration of survey data acquisition and processing systems, automation of chart production and maintenance systems, and improvement of technical and managerial procedures.

Automated Chart Production

Development of automated cartographic compilation systems is underway to improve charting production processes and to decrease the time delay between acquisition of survey data and distribution of the final product.

To expedite and improve the processing of data by available technology, C&GS has instituted research on the automation of portions of its data processing operation. Cost-effectiveness studies were used to reveal which areas of operation offered maximum opportunities for increased efficiency should automation be introduced. Studies indicated that an automated data system would achieve a balance between data acquisition and processing, permitting a reduction in the backlog of unprocessed data and providing a foundation for expansion to match increases in data flow.

Another research project initiated by the C&GS during the reporting period concerned the development of an informational system which would store, retrieve, and transmit information acquired with C&GS facilities but not used in its own products, and information subject to requests from users outside the C&GS. A study was performed to identify the types of data stored in C&GS working and archival files necessary for the production of its regular products. An inventory of data acquired by the C&GS as a service to other groups was also determined. Traditional requests to C&GS for various types of data were also summarized. From all of these studies, an information-handling system plan for the C&GS was developed, including a policy for handling special information required by the Environmental Data Service (EDS) and the National Oceanographic Data Center (NODC).

Hydrographic System

The need to automate survey data acquisition and processing activities is quite apparent. The slow hand-processing techniques in use have resulted in a backlog of unreviewed data and a consequent delay in producing safe, efficient nautical charts in a timely manner. Automation speeds the processing of survey data, allowing their distribution to the user while still reasonably current. Automation will be introduced aboard ships to permit real-time or near real-time digital logging and plotting, on-line and off-line data reduction, evaluation of data for computer program logic, and near real-time preliminary verification of survey integrity.

To take advantage of the benefits of data automation, the C&GS has sought to develop a shipboard digital hydrographic data acquisition system. Such a system, using a computer configuration, automated plotter, electronic navigation system, and digital echo sounder, has been tested aboard the USC&GS ship *Whiting*. The ship was guided along predetermined straight-line courses by computer-generated instructions to the helmsman. During the operation, time, depth, position, depth correction, and position correction data were logged in digital form in real-time to achieve a real-time plot of the depth at the vessel's location. Following each day's work, the analog depth record was checked and required changes applied to the digital record. Subsequently, the digital records—tapes and printouts—were forwarded to processing centers ashore for final automated smooth plot.

Additional research is underway on: (1) documentation of the experimental computer programs; (2) development and testing of improved computer programs and subroutines for the *Whiting* experiment; (3) design of an improved automated data system for C&GS hydrographic ships other than the *Whiting*; (4) development of an improved capability to input tidal data and other correction factors; and (5) development of effective means to filter various inaccuracies and noise from the digital echo-sounder data.

The C&GS initiated the development of a high-speed hydrographic launch system to expedite hydrographic surveys. Construction of a high-speed launch was completed in June 1968, and tests of overall system performance followed. These tests sought to determine suitable transducer arrangements and to evaluate basic sensor response during high-speed hydrographic survey operations. Recently procured data control units were used as an aid in developing an effective system to process the data—including accurate position information—acquired during a high-speed test survey. Survey data resulting from this test have been processed through final review and adjudged adequate for charting purposes. As a result of this success, a *Whiting*-type computer/plotter array has been ordered for the high-speed launch; testing of this latter system is anticipated to begin in September 1969.

OCEANOGRAPHY

Service Programs

The ESSA oceanographic fleet—vessels operated by the C&GS—conducts research studies and geophysical surveys which describe the ocean environment. These geophysical surveys involve systematic observations of physical and chemical oceanographic parameters; the survey results are then made available in publications or on maps for users interested in resource exploration, national defense, and scientific understanding of the ocean and its processes.

Tide and Tidal Current Observation and Prediction

The primary objective of the tide and tidal current observation and prediction program is to provide astronomical tidal prediction services for commercial, naval, and recreational interests. The program also furnishes data on physical processes relating to beach erosion and pollution control. The program establishes datum planes for referencing bottom soundings on charts and delineating legal shoreline boundaries.

A network of about 120 permanent gage stations is maintained for these purposes. Data from an additional 80 temporary gage stations, placed in selected operational areas each year to support hydrographic surveys, increase the effectiveness of the permanent network. All C&GS hydrographic survey vessels are equipped with portable gages, enabling them to establish tide stations in operating areas for the determination of tide corrections as soundings are made.

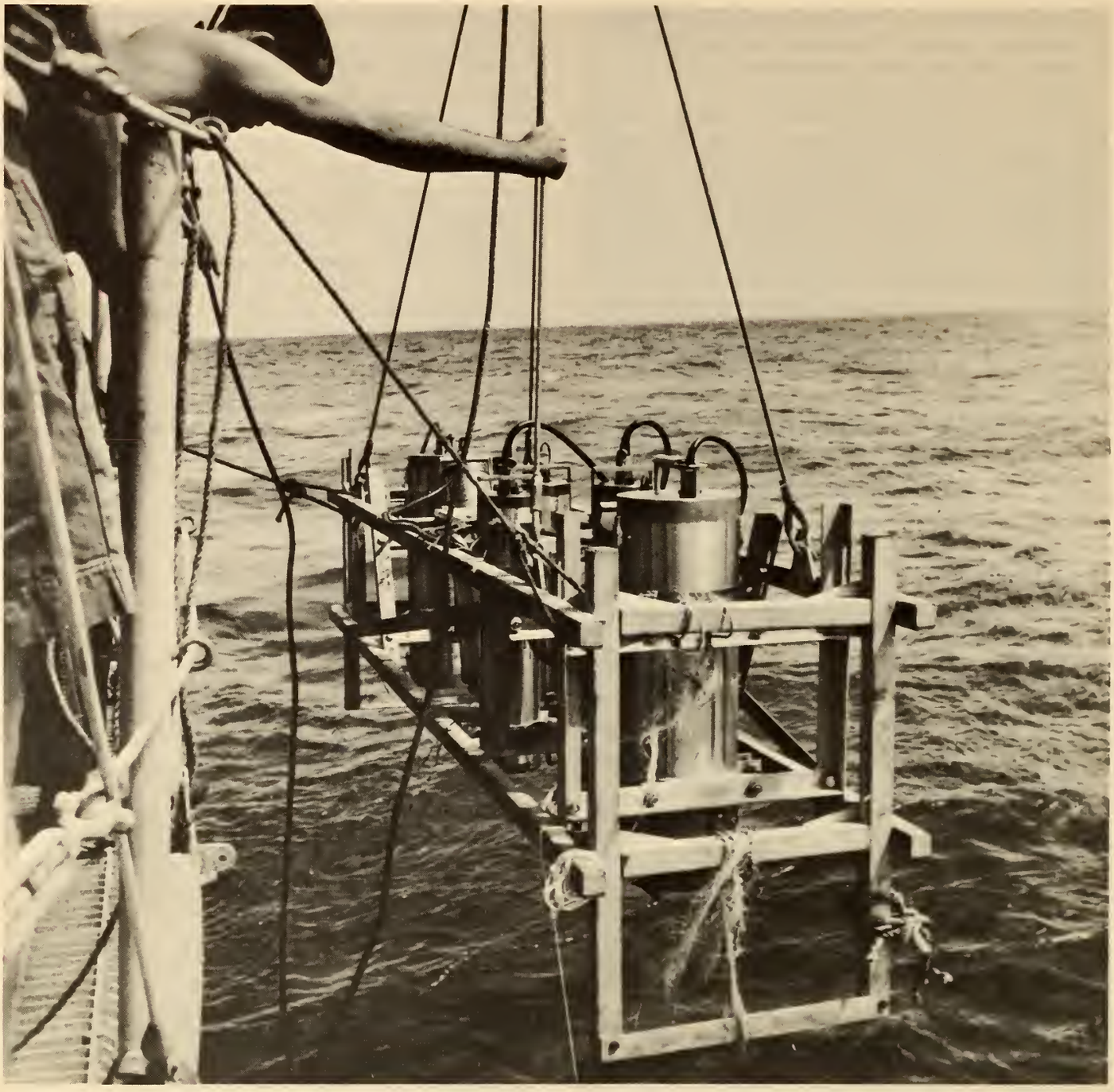
Data collected by the tidal gage networks provide predictions for the United States and its possessions; predictions for other parts of the world are obtained from various nations on a cooperative basis. Tables of the worldwide daily tide predictions are published annually in four volumes by ESSA—1 year in advance.

A systematic collection of tidal current observations is made in coastal waters, embayments, and harbors of the United States. Approximately 75 stations are occupied annually for periods ranging from 100 hours to a month. Based on the observational data collected, predictions are made of slack water times and maximum tidal current times, speeds, and directions. These tidal current predictions are published annually in two volumes. In addition, tidal current chart atlases are published for some major U.S. harbors and waterways. One vessel, the USC&GS ship *Ferrel*, operates exclusively for tidal current work, although current meters are carried on all C&GS vessels.

Bathymetric and Geophysical Mapping

Bathymetric mapping involves the systematic charting of sea bottom topography to provide information for the exploration and development of mineral and fish resources. Basic bathymetric maps at 1:250,000 scale are planned for the entire U.S. Continental Shelf. Larger scale bathymetric mapping of selected oceanic areas is planned to provide additional coverage for exploitation of marine resources. The bathymetric series will be constructed from both existing sounding data obtained from nautical charting activities and from newly generated data gathered specifically for that purpose.

While bathymetric maps are essential to the delineation of bottom topography, geophysical maps are also needed to provide a more complete description of the sea floor for scientific purposes and for better evaluation of resource potential. Intensities of the magnetic and gravitational fields of the earth and the subbottom configuration obtained by seismic profiling are measured simultaneously with depth measurements during oceanographic surveys. Maps of magnetic and gravity anomalies (the difference between actual measured values and theoretical regional field values) and subbottom structures are made at the same scale as the bathymetry, either separately or as overlays to the bathymetric map base.



Lowering of stereo pair deep sea camera into the ocean.

Research and Development Programs

Although the C&GS provides ESSA's service programs in oceanography, it shares research activities in the field with another ESSA component. This component, RL, has the primary responsibility for basic research in physical oceanography. Research work is performed by the Atlantic Oceanographic Laboratories (AOL), Pacific Oceanographic Laboratories (POL), and Geophysical Fluid Dynamics Laboratory (GFDL).

The objectives of both AOL and POL are to seek new knowledge of the Atlantic and Pacific Oceans, Gulf of Mexico, and Caribbean Sea. Scientists of both Laboratories study the influences and interactions of the oceans with their physical environment, extend the marine services and operations of ESSA, and apply knowledge gained to national needs for improvement of oceanographic investigative techniques and instrumentation. Oceanographic research in GFDL is directed toward fundamental understanding of

large-scale circulation systems of the atmosphere and oceans. This research on circulation will develop a comprehensive theory of geophysical fluid systems and processes. Such a theory could lead to improved short- and long-range weather predictions and could provide techniques to discover and test the means for large-scale weather modification.

Research activities of the RL in oceanography include structure and motions of the ocean, ocean circulation, land-sea interaction, and sea-air interaction.

Bering Sea Oceanographic Study

Among C&GS activities in oceanography underway during the past 2 years was a cooperative study with the Geological Survey of the bathymetry, gravity, magnetics, sediments, and currents of the northern Bering Sea of Alaska. This study involved collection of hydrographic and oceanographic survey data during the 1968 and 1969 summer seasons and subsequent issuance of bathymetric, gravity, and magnetic maps by the C&GS. The survey included hydrography, gravity, and magnetics at a line spacing of 1 to 2 miles. Over 200 sediment samples were taken and sent to the Geological Survey for analysis and processing.

Marine Observation Systems

During the reporting period, C&GS continued research on an oceanographic buoy system for measuring time dependent variables of the ocean. This system aims at solving problems of oceanic sensor design and construction; data storing, recording, and telemetering; power supply; placement; maintenance; and retrieval.

The Ocean Data Environmental Science Services Acquisition (ODESSA) buoy system, which consists of sensors for measuring current velocity and direction, temperature, salinity, and pressure, has been under development and is approaching operational status. The ODESSA system includes a radiotelemetry link with scheduled interrogations so that data can be accumulated on board or recorded remotely. One aspect of C&GS's research on this system was the adaptation of the system to deep ocean operations. The approach used involved adapting the signal links, container seals, and other features to deep ocean application and completing the final debugging of the original development. The system was given a series of laboratory and field evaluations, after which successive improvements were incorporated. Field tests were performed in the Potomac River and off Bimini Island in the Bahamas.

The success of the C&GS's three-point mooring of a stable deep underwater platform in 4,500 feet of water about 100 miles off the west coast during an endurance test in FY 67 and FY 68 prompted an analytical study in FY 69 of platform movement under different conditions of depth and currents, including the measurement and analysis of actual platform motions. The performance of the full-scale platforms was monitored for verification during the past Fiscal Year.

The Coast Survey Marine Observation System (COSMOS) ocean tide system includes the development of methods for measuring deep sea tides and other ocean characteristics. A pressure tide gage was placed and tested during the winter of 1968–69 on the COSMOS platform in the Atlantic Ocean, with another on the sea bottom underneath the platform; both gages recorded on the same recorder situated on the platform. Comparisons of recorded data indicated the value of using this platform as a base from which to measure tides. Accelerometers and tiltmeters were also placed on the platform to study platform motion.

A complete procedure for installation, positioning, and retrieval of COSMOS platforms was developed and tested in operations off Barbados in the West Indies during the summer of 1968. After debugging, the procedure was employed in the fall of 1968 and again in 1969 with additional platform installation.

Another phase of the C&GS's research into marine observation systems involves the COSMOS satellite telemetry studies seeking the development of position-locating equipment. This research is concerned with development of a practical buoy antenna and supporting buoy combination to transmit oceanographic and meteorological data to a land station by means of a synchronous Applications Technology Satellite (ATS). The Omega Position-Location Equipment (OPLE) was supplied by the National Aeronautics and Space Administration (NASA) and installed in a buoy furnished by C&GS. Following laboratory tests, the buoy was moored in the Atlantic Ocean off Miami, Fla., to explore the buoy-satellite communication link. Later, the buoy was made free-floating to explore the OPLE's buoy-tracking ability. Uninstrumented tests were also conducted. As a result of these tests completed in the summer of 1968, a new buoy hull was built. The buoy equipped with OPLE will eventually make data available from previously inaccessible sites. Extensive research into the existing state of buoy and buoy antenna design, buoy mooring, and buoy retrieval is currently underway.

Structure and Motions of the Ocean

Studies directed toward the structure and motions of the ocean were conducted by the POL on the state, processes, and dynamics of the Pacific Ocean, with emphasis on such large-scale features as seasonal or regional patterns; support was also given to microscale, short-term variability, and isolated phenomena studies. Programs during the reporting period stressed the study of circulation dynamics of ocean water masses, ocean current systems, heat budgets, salt budgets, and volume and mass transport.

POL scientists conducted joint research with the Department of Oceanography of the University of Washington in testing, through ocean experiments, hypotheses concerned with the propagation of semidiurnal internal waves to the open ocean. Oceanographic investigators at the University developed a theoretical model to describe the generation of internal waves by the surface tide wave as it impinges on the Continental Shelf. The model describes internal waves in terms of normal modes. By using the model, and knowl-

edge of local bottom configuration and density structure, it is possible to predict details of internal wave propagation seaward from the Shelf.

Oceanographic reseachers at the University, under Office of Naval Research sponsorship, performed computer simulations of the normal mode model to aid in the deployment of sensors. Instrumentation for the observation program was provided by the Navy. ESSA assigned the USC&GS ship *Oceanographer* to the project. The Joint Oceanographic Research Group (JORG) of POL is coordinating the observation program, specifying the experiments, and planning for data processing and analysis. Scripps Institution of Oceanography also participated during field operations of the observation program.

POL's investigation in FY 69 showed that at the experimental site—latitude 42° N.—standing waves of semidiurnal frequency are generated over the Shelf and free waves of the same frequency are propagated seaward. These internal waves satisfy the requirements of this experiment because they emanate from a well-defined source and propagate as a line of high energy at a known frequency in the spectrum. Details of their seaward propagation can be predicted. The normal mode model was tested by 11 days of measurement at the experimental site. Analysis of data is underway.

Field measurements supporting the Polar Front—North Pacific Intermediate Water Study, a study of physical and chemical structure being conducted by POL as a cooperative effort with Oregon State University, were extended westward to longitude 155° E. Data for fall and winter conditions were obtained for comparison with spring conditions measured in FY 68. Analysis of the unexpectedly complex structure of the Intermediate Water, directed toward determining its origin, development, and trajectory, continues.

Studies were made and reports prepared by POL on currents in the Tasman Sea—one on a previously unknown countercurrent of the East Australian Current, and the other on the speed and direction of bottom currents in the Tasman Sea measured for the first time. Measurements were made utilizing an automated current meter, an acoustic signalling device, and bottom photography.

Another study on the properties of the central North Pacific deep water at 3, 4, and 5 kilometers revealed a gradual warming, dilution of salinity, and reduction of dissolved oxygen in a general south to north direction. The report, based largely on ESSA's Scientific Exploration and Mapping (SEAMAP) Program data, included a proposed trajectory for the water which indicates a circuitous path for the extreme northern region.

Analysis of geostrophic data, supplemented with parachute drogue measurements, revealed a 37 percent reduction in the mass transport of the Alaska Stream from winter to late summer, whereas year-to-year variation during the same period is small. This variability is attributed to seasonal variations in atmospheric pressure patterns.

A study by POL scientists of temperatures and other properties of water confined to deep basins, trenches, and deeps off the west coast of Central and North America revealed an anomalous situation in the Panama Basin, suggesting either discernible heating of bottom water from geothermal sources or presence of an uncharted topographic barrier. As the latter seems improbable, the thermal gradient was used to develop a coarse flow pattern.

A more precise, new method for computing the mean vertical speed of sound through the ocean, applicable for echo sounding, and equations for utilizing the method in the central Pacific Ocean were published; the method is programmed for routine use at the C&GS's Pacific Marine Center in Seattle, Wash.

During the past Fiscal Year, the AOL completed a time series study of tracklines following the core of the Gulf Stream. An evaluation of the potential of orbiting spacecraft for mapping large-scale oceanic phenomena was also initiated with the objective of applying the observations to the core of the Gulf Stream.

A cooperative study—involving AOL, Sippican Corporation, and Humble Oil Corporation—was conducted in FY 69 on the use of bathythermograph observations for oil tanker transits between gulf coast and northeastern Atlantic coast ports to identify displacements of the core of the Gulf Stream. A long-range goal is to develop a technique that may be applied in other areas, particularly on routes to the Persian Gulf.

Ocean Circulation

Research in ocean circulation by AOL scientists involved the description of the dynamics and physical properties of the oceans, including advective and convective aspects of circulation and interactions of circulation with the atmosphere and the sea floor. Particular emphasis in FY 68 was directed toward circulation of waters that affect the environment of the U.S. east and gulf coasts. Preliminary analysis of Gulf Stream data obtained during monitoring of the 15° Celsius isotherm path showed a progressive wave pattern in the meanders. Data measurements acquired at ocean stations along a section off Charleston, S.C., at predetermined time intervals were reduced and data interpretations are underway. A study of horizontal divergence, using drogue data, was partially completed by AOL; a more comprehensive set of data was obtained in June 1968. Another AOL study completed was an investigation into the variation of water temperatures related to the passage of hurricanes.

In preparation for the Barbados Oceanographic and Meteorological Experiment (BOMEX), the AOL used COSMOS and tautwire buoy arrays (with ODESSA sensors), and salinity-temperature-depth (STD) time series from stationary ships for studies on the variability of different physical parameters, their coherence on various scales in three-dimensional space, and their relationship to atmospheric data obtained simultaneously. Gulf Stream and Florida Current variability research continued.

The GFDL contributed to investigations on the dynamics of ocean circulation through the development of numerical models. Calculations for these investigations utilized simple ocean basin topography. More detailed numerical models

were constructed and tested during the reporting period using actual shorelines and bottom topography of the world's major oceans. Both temperature and salinity were included to permit an accurate computation of density. Wind stress, temperature, and salinity were specified at the surface, based on values taken from climatological atlases and with seasonal variations considered. The grid size employed a final resolution of 1° intervals of latitude and longitude. Special finite difference nets were developed to resolve accurately the very fine structure which develops in the circulation patterns within regions of nongeostrophic flow at the Equator and along the side boundaries. Calculations were performed for a wide range of governing parameters; data obtained have provided researchers with a basic understanding of the physics of ocean circulation.

An understanding of the Gulf Stream and similar currents is basic to knowledge of the oceanic circulation. A simplified numerical model was used to determine the factors that affect the path of the Gulf Stream and the variations of observed transport. The model included both the effect of density structure and bottom topography. A stability study also was performed to trace the origin of Gulf Stream meanders. A numerical approach to the stability calculation permitted extremely realistic profiles.

Land-Sea Interaction

Investigations were performed by the AOL during the last 2 years that involved an analysis of interaction phenomena at the land-sea interface, including the effects of wind, wave, tide, and currents and the development of predictor equations for forecasting these phenomena.

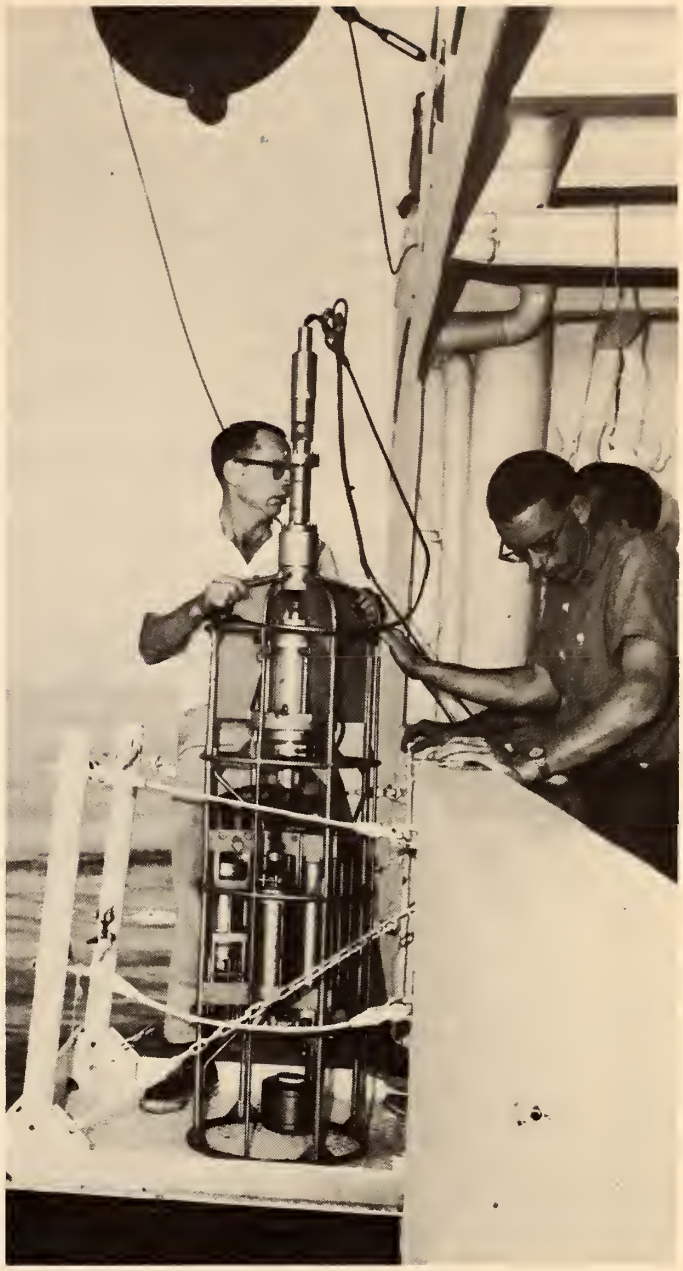
The AOL also conducted investigations that involved the development of field documentation and analysis of selected interaction phenomena at the land-sea interface to increase understanding of the effects of winds, waves, tides, and currents on beaches, inlets, and surface of the continental shelves; such investigations included the development of analytical expressions for the observed interactions and predictor equations for forecasting the selected interaction phenomena.

In FY 69, AOL researchers obtained comprehensive movie-film data on the runup associated with breaking waves at Virginia Beach, Va. From an analysis of the data, theoretical equations for wave runup were developed. Researchers also studied the dispersal of sand grains by inlet currents at Rudee Inlet in Virginia Beach, using radioactive sand tracers and sand grains coated with fluorescent dye. Coincident with obtaining tracer release-and-recovery data, AOL scientists obtained data on net fluid force vectors in the study area.

Sea-Air Interaction

The direction of AOL research programs in sea-air interaction during the last 2 years involved the study of exchange processes—heat, moisture, momentum, and mass—between the oceans and the atmosphere. Ocean-atmosphere interaction studies were pursued in two distinct efforts—to develop better models and to provide better instrumentation. A numerical model was developed for the ocean-atmosphere boundary layers which extend from depths of a few hundred meters in the ocean to heights of about a kilometer in the atmosphere. The principal processes included in the model are eddy fluxes in humidity- and salinity-dependent stratified flows, mixing caused by wind-generated waves at the sea surface, and cloud-dependent radiative heating. The interface conditions require continuity of eddy shearing stress, velocity, and temperature; saturation of the air; and balance between evaporation and salinity at the interface.

Parallel to model development was a program for instrument development to improve measurements of all important parameters in the lower atmosphere which enter numerical model development. The instrumentation is designed to



Preparing salinity-temperature-depth (STD) sensor for lowering into the ocean.

observe wind speed, humidity, and temperatures. Tethered balloons carry the instruments aloft where they transmit data to a ship below through multiplexing techniques. Field data obtained as vertical profiles and time series were analyzed by digital computers. A fast Fourier transform program was developed for the GFDL–1108 computer, permitting calculation of energy spectra and cospectra.

The AOL's storm surge group is working on models involving storm-surge resonance phenomena with the passage of tropical storms traveling parallel to the coast. Using a geometric-optics technique for resonance modes, indications are that typical storms with a maximum wind radius on the order of 30 to 50 miles may be too large to generate progressive edge waves as forecast by past theoretical work. Computer runs of models for storms with a maximum wind radius of 15 miles do show generation of progressive edge waves.

A preliminary field project, the Atlantic Trade Wind Experiment (ATEX), was conducted near Barbados in the West Indies in February 1969, followed by the initial phases of BOMEX in May 1969. The Sea-Air Interaction Laboratory of AOL contributed significantly to both major field experiments. The Laboratory coordinated U.S. participation in ATEX. The USC&GS ship *Discoverer* carried out an intensive sea-air interaction program for ATEX in collaboration with two German—*Planet* and *Meteor*—ships and one British research vessel—*Hydra*. The four ships positioned in a 400-mile triangular array southwest of the Cape Verde Islands, drifted with the tradewinds for 3 weeks in late January and early February of 1969, taking intensive samples of the lower atmosphere and upper ocean layers with specialized instrumentation to investigate tradewind inversion. Scientists from several countries and the United States participated aboard the *Discoverer*, conducting investigations related to atmospheric electricity, radiation, chemical oceanography, and marine biology.

The Laboratory also performed an observation program during the BOMEX project; this program involved an investigation of the planetary boundary layers from ESSA's participating ships. Scientists also established a full surface observation program on the other participating research ships. Direct heat flux measurements were attempted, using recently developed instrumentation at Scripps Institution of Oceanography. The technique consists of observing radiometrically the effective temperatures at two different levels very close to the sea surface, and applying molecular diffusion theory.

Satellite photographs were used in the study of low-level convective cumulus cloud patterns in the eastern Caribbean Sea and western tropical Atlantic Ocean. These patterns were related to observations of temperature, pressure, wind, and other meteorological parameters obtained during ATEX and BOMEX. Ocean thermal data obtained by ESSA research vessels were correlated with Gulf Stream data obtained by Nimbus 2.

7 TELECOMMUNICATIONS AND SPACE SERVICES

The Telecommunications and Space Services of ESSA, rendered through its Research Laboratories (RL), provide descriptions and predictions of the state of the earth, its atmosphere, and surrounding space that are pertinent to electromagnetic wave propagation and its applications to telecommunication and remote sensing, as well as those pertinent to vehicular travel in the upper atmosphere (ionosphere) and space.

The electromagnetic spectrum is a limited resource that supports millions of telecommunication channels simultaneously when used efficiently. Efficient use of the spectrum involves not only frequency sharing, but also sharing of time, space, polarization, and other factors. The term *electrospace* has been coined to designate all factors involved in efficient use of electromagnetic waves for telecommunications. ESSA's Telecommunications and Space Services help users make more efficient use of the electrospace by providing reports on actual radio conditions and predictions of expected conditions in the troposphere and ionosphere that distort, refract, and change the characteristics and strength of radio waves, and by providing research and consultative services on those aspects of telecommunication systems design that are affected by environmental factors and electrospace use considerations.

Other parameters of the environment also affect the characteristics of radio waves. For example, meteorological parameters in the lower atmosphere—such as barometric pressure, temperature, and water vapor—affect the refractivity of the atmosphere, and thus the direction of radio waves.

The radio-reflecting ionosphere is modified by bombardment of solar X-rays, ultraviolet light, electrons, protons, and by disturbances in the earth's magnetic field. Certain ionospheric conditions enhance long-distance transmission of radio waves by reflection between the earth and ionosphere; other ionospheric conditions hinder radio wave transmission or block certain communications circuits, requiring the user to shift to less efficient telecommunication systems. The RL have programs to measure the ionosphere through continuous solar and geophysical observations in the upper atmosphere and space.

A series of radio quality and ionospheric condition predictions are issued on a scheduled basis, varying from four per day to one per week. Ionospheric predictions of wave propagation conditions on a worldwide or regional basis are produced on a semimonthly and monthly schedule.

Radio-circuit predictions as reported by RL are used extensively by the telecommunications industry throughout the world. These predictions are particularly important in this country because of the national expenditure of $20 billion annually in the telecommunications field. Users of ionospheric predictions include 2,200 Government organizations and 1,200 commercial and general public subscribers.

Transmission of radio waves by means of the troposphere is affected by weather and climate: Precipitation scatters and attenuates radio waves, especially at the higher frequencies; inversions may trap radio waves, causing enhancement or attenuation depending upon the geometry involved; turbulence causes scatter of radio waves, but can be used to obtain transmissions for hundreds of miles beyond the line of sight. The RL predictions of tropospheric radio propagation conditions are mainly in the form of equations or computer programs involving parameters which relate to such environmental characteristics as refractive index gradient and dispersion, turbulence, precipitation, and terrain irregularities.

The RL also provide forecasts and data on disturbances occurring in space and in the earth's upper atmosphere as a consequence of unusual electromagnetic and energetic particle radiation emitted from the sun. Disturbances on the sun, such as solar flares, are associated with the emission of large quantities of radiation in the optical, radio, and X-ray portions of the electromagnetic spectrum and the ejection into space of both energetic electrons and protons. Although the earth's atmosphere protects life on the surface of the earth from most of this high-energy solar radiation, such radiation presents hazards to both man and

equipment as man attempts to use the upper atmosphere and space environment for operation of supersonic aircraft and manned and unmanned spacecraft. Space disturbance forecasting includes prediction of impending solar activity and its effects; such forecasts require continuous monitoring of the sun at both optical and radio wavelengths, and also monitoring of ionospheric effects of solar activity. Like telecommunications disturbance forecasting, RL's Radiation Measurement and Forecasting Service is a recent outgrowth of research activity in this field.

The research and development (R&D) activities of the RL in Telecommunications and Space Services involve the following research fields: telecommunications (environmental factors in communications technology), aeronomy and upper atmosphere, and space environment.

With the advent of space exploration during the past decade, the regions beyond the atmosphere have come under intensive investigation. Man is protected from dangerous solar radiation by the shielding effects of the earth's atmosphere and magnetic field. However, at the planned operating altitudes (60,000 to 80,000 feet) of supersonic transports (SST) and for any manned and unmanned space flights, solar radiation must be monitored and predicted to protect man's health for operational functions and to maintain communications between space vehicles and earth. To continue improvements of its operational service programs, ESSA's RL conduct various research programs into the physics and dynamics of the upper atmosphere and on those exceptional environmental phenomena that affect man's operation in the high altitudes and space environment.

TELECOMMUNICATIONS

Research programs in telecommunications necessitate examination of all pertinent elements of the environment. Variations in environmental parameters cause variations in prediction conditions; therefore, telecommunications research not only includes use optimization of the radio spectrum, but to a large extent concerns itself with environmental change. These research programs relate to other programs of ESSA because of the importance attached to telecommunications in data acquisition and dissemination.

Telecommunications research in ESSA is conducted within the RL by the Institute for Telecommunication Sciences (ITS) and the Wave Propagation Laboratory (WPL).

The ITS serves as the central Federal agency for the acquisition, analysis, and dissemination of information on propagation of electromagnetic waves, on electromagnetic properties of the earth and its atmospheric environment, on dynamics of electromagnetic noise and interference, on information transmission and antennas, and on means for more effective use of the electromagnetic spectrum for telecommunications.

The ITS also conducts research and provides research services to improve national utilization of the electromagnetic spectrum for telecommunications, to determine the effects of the earth's variable surface and changing atmosphere upon telecommunications, and to broaden technical understanding of these environmental factors requiring national telecommunications policy decisions.

The electromagnetic spectrum extends from radio to X-ray waves, with operational telecommunications conducted by users of channels between about 10,000 and 40 billion Hertz, the present limit of radio wave frequencies allocated by the International Telecommunications Union (ITU). The number of channels this allocation provides, considering that an ordinary two-way telephone conversation requires two channels of 3,000 Hertz each, is not great. The 40 billion Hertz now allocated represents 13 million channels, each 3,000 Hertz wide. With 200 million people in the United States and 3.5 billion people in the world at present, 13 million channels may not be sufficient to meet the growing communications demands of everyone.

The need for more channels is critical. Improved utilization of this limited portion of the spectrum is the only available solution presently to overcrowding. However, environmental research should permit eventual use of the spectrum range in the higher frequencies (shorter wavelengths) as those environmental factors in the lower atmosphere limiting use of the higher frequencies are overcome.

One major objective of research in telecommunications is to develop and apply methods for optimizing use of specific portions of the radio spectrum, whether influenced by the ionosphere or by the troposphere and earth's terrain. These communications technology studies include, for example, research on multiplexing to enlarge the amount of information carried by a given channel and studies of improved cable communications as an alternative to broadcast propagation methods.

Ionospheric Telecommunications Program

Work in ionospheric telecommunications was carried out in five major program areas: propagation of frequencies below 1.5 MegaHertz, high frequency propagation, modification of ionospheric currents, ionospheric predictions, and communications technology.

Propagation of Frequencies Below 1.5 MegaHertz

The objectives of research in propagation of frequencies below 1.5 MegaHertz are to devise and verify methods of predicting several environmental effects: Normal propagation loss and phase delay of electromagnetic signals at frequencies less than about 1.5 MegaHertz as a function of frequency, direction of propagation, latitude, time of day, and season; electrical constants of the ground and determination of the appropriate ionosphere parameters for use in such predictions; and effects of natural ionospheric irregularities and other disturbances—such as those caused by solar flares, polar cap events, and nuclear explosions—on the propagation of signals of frequencies less than about 1.5 MegaHertz.

Research was directed during the reporting period toward a variety of topics. Among the studies undertaken was one conducted aboard the USC&GS ship *Oceanographer* which yielded data on the daily variations of very low

frequency (VLF) signals, especially fading patterns caused by multimode interference. Another study, initiated for the Air Force, involved a series of measurements of ground-wave transmission loss at frequencies between 400 kiloHertz and 15 MegaHertz over path lengths up to 100 kilometers. Still another study was initiated in cooperation with the Defense Atomic Support Agency (DASA) and involved a pulsed low frequency (LF) skywave experiment to determine D-region ionospheric reflection coefficients as a function of frequency and, subsequently, D-region electron density profiles. Investigations of ground-wave propagation over irregular inhomogeneous terrain showed that frequently the effect of abrupt conductivity changes is masked by the effect of terrain changes.

In FY 69, data on 40 atmospherics recorded simultaneously in the United States and Japan were analyzed and exchanged. Experimental evaluation of phase errors in long-range aid to navigation—Loran-D—radio navigation systems was also carried out for the Air Force in FY 69. Theoretical evaluation of phase corrections for three-dimensional propagation over irregular terrain continued.

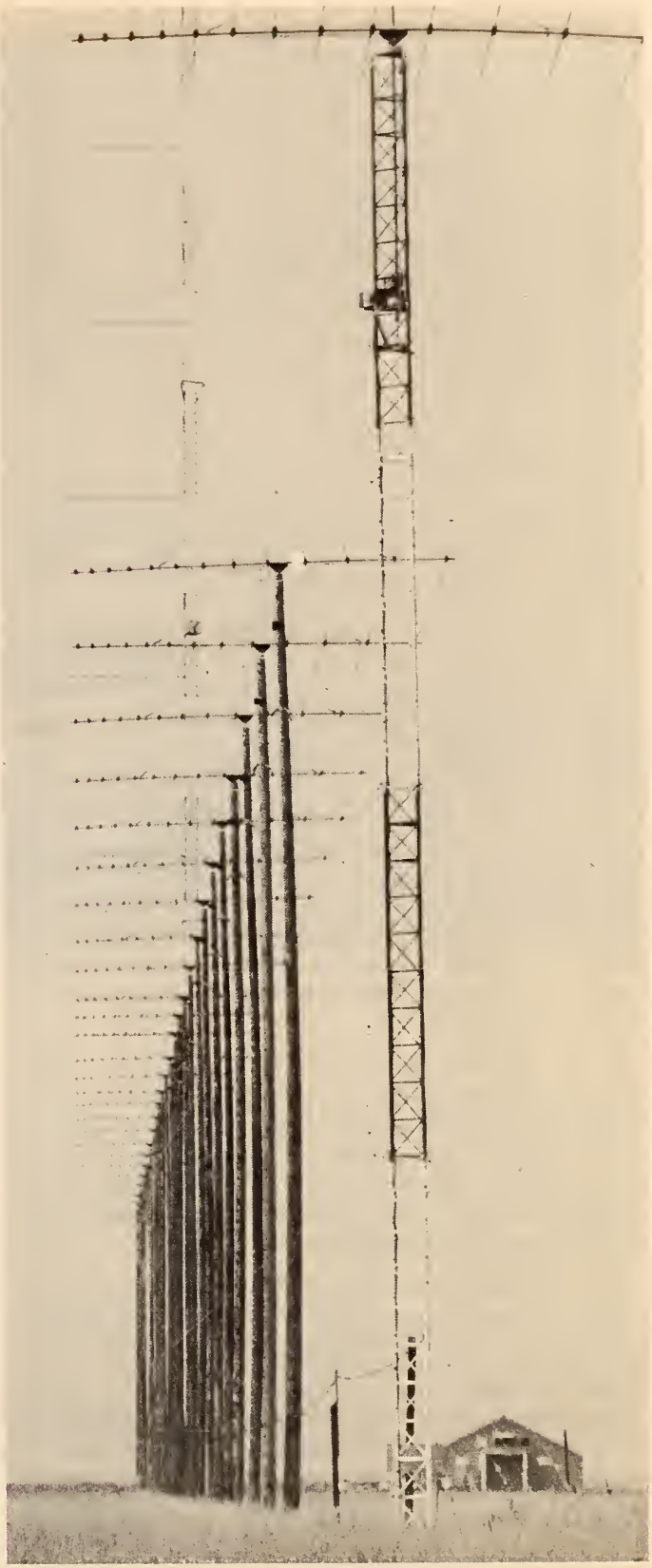
High Frequency Propagation

During the past 2 years, ITS scientists conducted theoretical and experimental studies of radio signal propagation at frequencies from about 2 to 50 MegaHertz as part of the high frequency (HF) propagation telecommunication studies. These studies had the following objectives: to describe the variable characteristics in time and space of the ionosphere as an inhomogeneous. dynamic medium; to determine the effects of irregular terrain on the radiation, reflection, and scattering of radio signals; and to predict the frequency, time, and spatial characteristics of HF telecommunication signals.

Ionospheric oscillations with a period of about 3 minutes have definitely been associated within a radius of about 200 kilometers with centers of severe weather indicated on weather-radar maps. Studies of the interaction of atmospheric waves with the ionosphere show that photochemical effects are as important as dynamical effects in the production of E-region irregularities.

A coordinated HF propagation experiment was conducted from August 1966 through June 1968. Data were collected on 5 days of each month with several different observational techniques. Results include validation of the three-dimensional ray-tracing program as an accurate tool for simulation of ionospheric propagation, development of a technique for accurately estimating the range to a distant transmitter, and establishment of a relationship between the quality of radio direction-of-arrival determinations and the characteristics of ionospheric radar records made simultaneously.

In FY 69, data from the 2-year coordinated ionospheric experiment were analyzed, an atlas of observed ionospheric backscatter radar records was being compiled, and a computer program was prepared involving simulated effects of traveling ionospheric disturbances.



Vertical-horizontal array of the ionospheric radar receiver on Table Mountain (near Boulder, Colo.), used with a radar transmitter for ionospheric and sea-state studies.

Modification of Ionospheric Currents

Ten balloons were launched by Earth Sciences Laboratories (ESL) scientists at Eielson Air Force Base near Fairbanks, Alaska, to determine the energy spectra of precipitating electrons that modify the ionosphere conduction in auroral electrojet currents; data on three events of workable magnitude were obtained. An understanding of the energy spectra of precipitating electrons will reveal to what extent micropulsations observed on the ground are attributable to modification of ionospheric currents caused by increased conductivity brought about in the particle bombardment process.

Ionospheric Predictions

The preparation and dissemination of ionospheric predictions and data for military and civilian radio; for scientific uses in satellite, missile, and space programs; and for other scientific and engineering applications are performed by ITS. Ionospheric data are obtained from cooperating ionosphere-sounding stations in this country and abroad, and from stations operated by program personnel or through contracts. The RL and other Federal agencies use ionospheric predictions to provide experimental transmissions or engineering services, to improve prediction methods, and to apply predictions to their requirements.

Numerical mapping techniques for predicting the global variations of the ionosphere were extended to include seasonal and sunspot cycle variations. Similar numerical techniques were applied to sporadic E—a thin layer in the lower part of the ionosphere whose erratic occurrence results in uncertain propagation of radio signals reflected from the ionosphere.

In FY 69, three-dimensional prototype electron density maps were prepared. An improved method of updating regular monthly predictions of ionosphere characteristics was also accomplished. Improvements in systems performance prediction were made through investigation of ionospheric absorption, antenna gain, propagation mechanisms, signal-to-noise thresholds, and short-term predictions.

Major advances were made in the computer-programmed prediction model employing the ionospheric parabolic-layer theory used for communications planning and operational purposes in all military services.

Improvements were also made in the calculation of the radio transmission loss by taking into account a winter anomaly and changes in absorption with latitude.

Communications Technology

Beneficial technical information to improve telecommunications and to make fuller use of the radio frequency spectrum within the ionospheric modes of propagation became available during the reporting period. Advancement in technical information was the result of basic and applied research in the fields of antennas and information transmission and the design and evaluation of telecommunication equipment and systems. Technical data, services, and recommendations on the Nation's ionospheric telecommunications activities were provided to industrial, governmental, and scientific organizations by ITS.

A laboratory instrument which accurately simulates the effects of the ionosphere on a propagated signal was completed in FY 69. The mathematical model which was the basis for the instrument has been validated by comparison with measurements over actual ionospheric paths. A model and simulator for HF atmospheric radio noise was also developed and integrated with the ionospheric simulator during FY 69. These simulators permit communication equipment to be laboratory-tested, minimizing the need for expensive field testing.

A major effort during the past 2 years was devoted to the development of a system for predicting short-term variations in ionospheric telecommunications performance, with initial emphasis placed on detection, warning, and prediction of effects associated with solar disturbances. In FY 69, additional communication-oriented parameters were included in the short-term forecasts through further study of users' requirements; direct user access to the timesharing computer was also provided.

On July 1, 1968, the Telecommunications Disturbance Forecast Center at Fort Belvoir, Va., was replaced by a real-time system which used a timesharing computer at Boulder, Colo., to forecast the probability, time of occurrence, duration, and magnitude of short wave fadeouts, polar cap absorption events, and magnetic storms and their effects on telecommunications systems.

An investigation of ways to provide a nonradiating communication link for use on moving high-speed railroad trains was undertaken for the Department of Transportation (DOT). Promising results were obtained with the so-called Goubau or "G" line, a one-wire line on which energy propagates in a surface-wave mode of low attenuation. The method devised was field-tested to determine the effects of severe weather and other environmental factors, line-coupling devices, and line supports on the performance of the system.

A search continued in FY 69 for better theoretical receivers, given time-varying specular and scatter multipath fading models.

Verification of the modulation effect on the spectral response of radar return pulses in clutter was made for the special case of one resonant scatterer among many nonresonant scatters.

A systems plan was prepared in FY 69 for the development stage of the Integrated Global Ocean Station System (IGOSS). This System will provide communication of meteorological and oceanographic data from buoys in the open sea to shore locations.

A surface-wave launcher used to transfer radio frequency signal energy from conventional coaxial cable to the surface-wave line.

Tropospheric Telecommunications Program

Work in tropospheric telecommunications was carried out in six major program areas: information transmission and analysis, tropospheric systems design and performance, electromagnetic interference environment, tropospheric propagation predictions, spectrum utilization research, and tropospheric physics.

Information Transmission and Analysis

The information transmission and analysis program is concerned with developing techniques and instrumentation for measurement, analysis, and laboratory simulation of tropospheric communication channel characteristics. These techniques and instrumentation provide an economical and reproducible way of evaluating in the laboratory the effects of channel characteristics and antenna diversity arrangements on information transmission and the performance of modulation-demodulation systems.

Channel characterization measurements for wideband frequency-modulation and frequency-division-multiplexing systems were begun during FY 68, using a pseudorandom analog test signal to develop the transfer function of the test channel for both amplitude and phase characteristics. High-speed digital time-series analysis was utilized to develop the statistical behavior of the channel characteristics for laboratory channel simulation.

During the reporting period, a considerable amount of channel characterization data was obtained over tropospheric circuits operating in line-of-sight, diffraction, and scatter modes of propagation on wideband communication circuits in Western Europe and Southeast Asia. Performance index data for both voice and data operation were obtained simultaneously with the characterization and propagation data collection.

Several improvements in data processing and analysis systems were formulated in FY 69 to effect an interface of special-purpose analysis instrumentation with general-purpose digital computer systems in the RL's Computer Division.

Tropospheric Systems Design and Performance

The design and performance analysis of telecommunication systems operating in the troposphere include taking account of the characteristics of the medium, presence of other signals (natural and manmade noise), type of modulation, and characteristics of the terminal equipment. Such systems usually involve electromagnetic propagation along the earth's surface and through the atmosphere, but they may also include cable transmission or acoustic propagation. An important part of theoretical research and experimental application involves the study of modulation techniques best suited for particular systems.

Among the research efforts pursued by ITS scientists is a project to permit more efficient use of educational television and radio channels. Time-diversion and frequency-division multiplexing can substantially enlarge the amount of information carried by a given channel. By employing a variety of subchannel modulation techniques, simultaneous transmission of analog and digital data is permitted and signal-to-noise ratios are improved.

The design of a digital communication system for the National Crime Information Center of the Federal Bureau of Investigation was undertaken. This system links large digital computers throughout the Nation, permitting ready access to vital law enforcement data.

Electromagnetic Interference Environment

Studies which define quantitatively the characteristics of the electromagnetic interference environment arising from natural and manmade radio noise and unwanted signals are conducted by ITS. Information is provided on the environmental influences affecting systems for improving practices of spectrum conservation and utilization.

During the past 2 years, methods were developed for making theoretical studies of the effect of radio noise on the reliability of digital telecommunication systems that also permitted the evaluation of error rates for particular systems operating in the presence of both atmospheric and manmade noise. Mathematical modeling was developed to obtain statistics of the noise process for use in predicting systems performance. Additional verification, using a broader range of noise samples, was required for confidence in the model. To obtain noise samples from which the various needed statistics were found, a development program provided a laboratory recorder which operated in communication bandwidths and over large dynamic ranges to permit using the recorded noise samples for noise analysis purposes and for systems testing in a channel simulator.

A specially equipped mobile noise laboratory was used for studying manmade radio noise. The upper frequency limit of its radio noise measurement capability was extended to 250 MegaHertz with the addition of channels at 100 and

One element of a two-dimensional antenna array used in a study of the random distortion of wave fronts of signals propagated through the turbulent atmosphere.

250 MegaHertz; work was started on equipment to extend the frequency range further into the ultrahigh frequency (UHF) portion of the spectrum. Using the mobile noise laboratory, manmade radio noise data were collected and analyzed for the writing of a computer program to provide correlation of noise data with population and vehicle densities. Studies are continuing on ways to determine applicable predictors for estimates of the manmade noise parameters required for systems designed to overcome radio and television interference.

Tropospheric Propagation Predictions

Programs in tropospheric propagation predictions during the reporting period involved the development of physical and mathematical models for predicting the performance of tropospheric telecommunications. A tropospheric propagation prediction model that covers a wide range of frequency, distance, antenna height, and terrain types was tested and revised by ITS scientists to obtain improved agreement with data from an extensive field measurement program. The model is used to predict and evaluate the performance of communication networks.

Theoretical studies to calculate effective reflections of the complicated structure of electromagnetic fields above irregular terrain were underway and mathematical models were being developed that adequately fit the actual situation.

Another project involved the development of a mathematical model to describe the scattering of radio waves by precipitation in clouds and predicted the resulting interference between satellite and terrestrial telecommunication systems sharing the same radio frequency.

Additional projects were underway, including a study of the characterization of radio channels and the information capacity of telecommunication systems, and a study to develop and test a program to simulate pulse code modulation (PCM) systems.

Spectrum Utilization Research

Research in spectrum utilization focuses on the development and application of theoretical and experimental methods to make optimal use of those specific portions of the radio spectrum primarily influenced by the troposphere and by terrain. Within this ITS program, three subprograms of research are pursued: terrain effects and tropospheric point-to-point communication systems, atmospheric effects on microwave communications systems, and frequency-sharing and spectrum utilization problems.

To aid ITS's Tropospheric Propagation Predictions Group in the determination of transmission loss, analyses of extensive propagation measurement results over irregular terrain at frequencies between 20 MegaHertz and 10 GigaHertz were performed and supplied in FY 68. Analyses of data obtained from a microwave link in Ohio suggest the possibility of prediction fading from synoptic weather information; studies were undertaken to explain the absence of significant distortion of nanosecond pulses observed over a line-of-sight link.

Frequency-sharing studies were made between land mobile and television broadcasting; a mathematical model was developed to study the difference of path-to-path correlation in irregular terrain between broadcast and land mobile operations.

Extensive support was provided to the Department of Defense (DOD) agencies in tests and evaluations of wideband communication links in Southeast Asia and in Europe during FY 68. Further assistance was provided by the ITS to DOD agencies in connection with the design, installation, and testing of wideband communication links throughout the world, including work on performance standards, methods of data collection, and tests of angular diversity performance for the Army Strategic Communications Command.

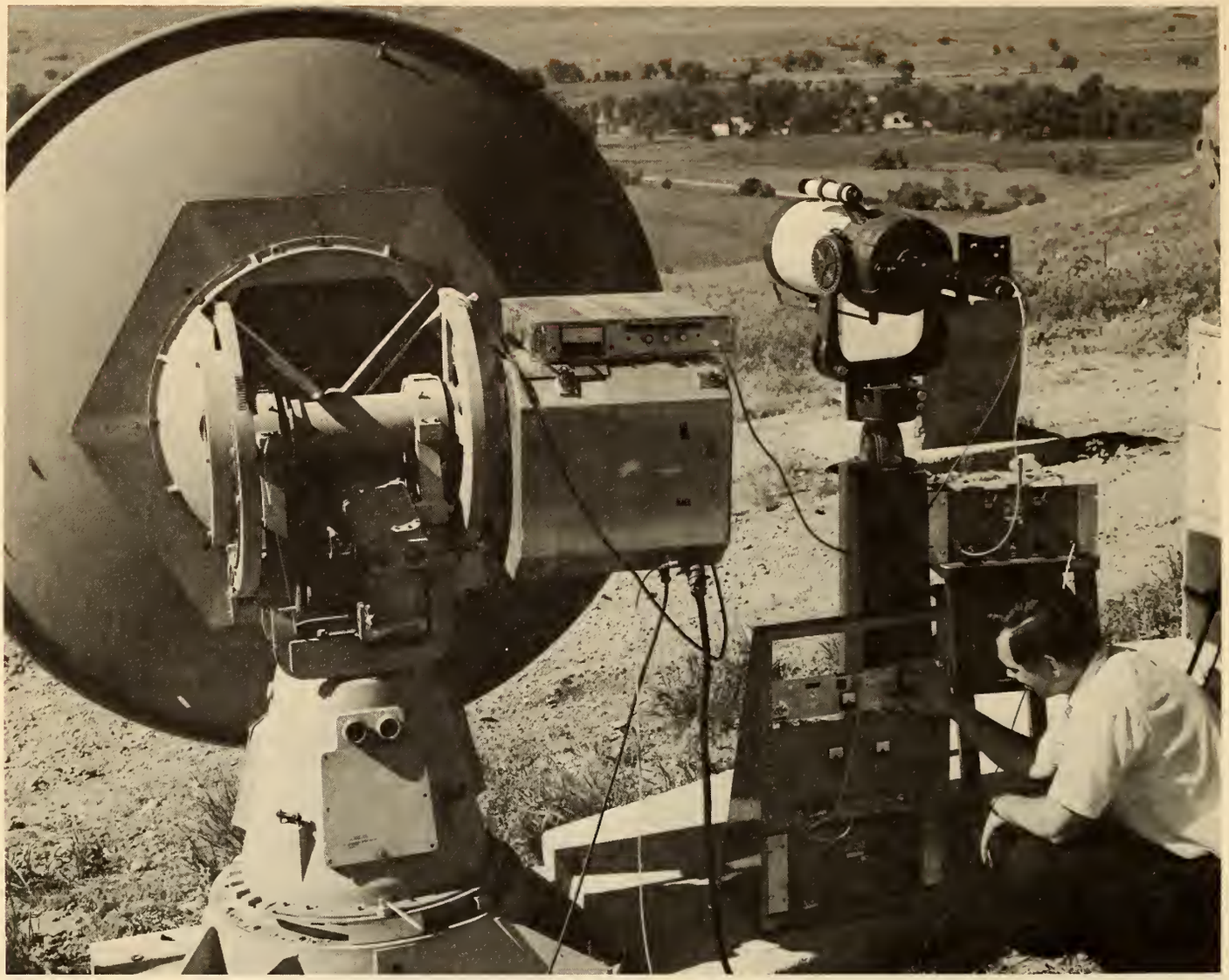
Tropospheric Physics

Tropospheric physics studies include research on the effects of the troposphere on the propagation of electromagnetic waves at frequencies above 300 MegaHertz. Emphasis in research is placed on the signal-phase distortion imposed by the atmospheric medium, on the evaluation of limits imposed by atmospheric turbulence on the accuracy of rocket- and satellite-tracking systems, and on the accuracy determination of electromagnetic distance- and angle-measuring systems used in geodesy and seismology through studies of the tropospheric refractive index structure. Techniques are also developed for phase stabilization over tropospheric scatter, line-of-sight, and satellite relay paths.

During the reporting period, research was underway on the analysis and interpretation of data obtained in a series of 10 major propagation experiments designed to study several types of atmospheric errors in missile- and satellite-tracking systems. These experiments were sponsored jointly with the Air Force's Electronic Systems Division, the Avionics Laboratory, and the Cambridge Research Laboratory.

Personnel of the ITS's Tropospheric Physics Group participated with the Millimeter Wave Propagation Group of the WPL in an experimental determination of the usefulness of millimeter-wave sky temperature data as refraction error correctors in radio-tracking measurements. The experiments included side-by-side operation of several radiometers and concurrent-range variation measurements over the slanted 65-kilometer ocean path in Hawaii previously used in experiments during 1967.

An investigation was made into the correlation between phase-of-arrival variations observed in the slanted-path, radio-tracking configuration and the corresponding spatial variations in atmospheric refractive index observed with an airborne microwave refractometer. Theoretical research at the University of Michigan has predicted a useful correlation of these two variables. The first measurements to test the theory were made in April 1968 over the same slanted 65-kilometer path in Hawaii. In conjunction with the Hawaii field tests, experiments were conducted to determine the effects of radio frequency separation on the relative behavior of phase and amplitude fluctuations of signals propagated through the troposphere. These experiments were conducted



Adjusting the receiving instrumentation used in radio-optical dispersion studies in the vicinity of Boulder, Colo.

in response to the increasing need for basic information to use in designing high-rate digital-type telecommunication systems. The results were subjected to cross-spectrum and coherence analysis to provide a comprehensive comparison of phase and amplitude characteristics at two closely spaced microwave frequencies.

Environmental Factors for Communications and Remote Sensing

The WPL acts as the focal point for wave propagation research aimed at the extension of telecommunication capabilities into higher frequencies, including optical waves, and develops new applications for electromagnetic remote sensing of the geophysical environment. Laboratory research concentrates on studies of telecommunication capabilities, frequency limitations, remote sensing techniques, and sound wave propagation in the atmosphere.

Optical Wave Propagation

Theoretical and experimental studies of the interaction of electromagnetic waves at optical and near infrared frequencies with the lower atmosphere included investigation of the usefulness of these frequencies for telecommunication purposes and as a means for remotely sensing the physical properties of the atmosphere. Observations of atmospheric amplitude scintillation, beam spread, and beam wander of a 0.63-micron laser source were completed over horizontal paths from 5 to 145 kilometers during the reporting period by WPL.

In another study, simultaneous measurement of laser beam scintillation and atmospheric turbulence revealed that the intensity scintillations saturate and do not increase above a certain maximum value even though the turbulence continues to increase. In FY 69, the intensity scintillation saturation phenomenon was further investigated. Scintillation and beam spread measurements of a 10.6-micron source

were carried out, and the longitudinal and transverse phase fluctuations in visible and infrared beams caused by the atmosphere were measured.

A two-color distance-measuring instrument was improved to increase its range and accuracy; an accuracy of 3 parts in 10^7 in optical path length measurement has been achieved over a 5-kilometer path. It is planned to employ the instrument for earth strain measurements in the vicinity of Denver, Colo., and elsewhere.

Construction was started on a three-wavelength distance-measuring instrument capable of measurements to an accuracy of a few parts in 10^8 over path lengths greater than 50 kilometers.

Submillimeter Wave Propagation

Theoretical research, both laboratory and field, was conducted during FY 68 and FY 69 in WPL on the use of millimeter, submillimeter, and far infrared wavelength electromagnetic waves (ranging from 10^{11} to 10^{14} Hertz) for telecommunications and remote sensing of the geophysical environment. More precise knowledge of atmospheric attenuation characteristics of water vapor, carbon dioxide, and nitrous oxide bands in the 1- to 25-micron range was obtained. The effect of line shapes on the continuum of water vapor absorption has been compared with recent data to describe attenuation over long paths.

The HCN and H_2O lasers have been designed, constructed, and placed in operation to provide sources of submillimeter waves. Detectors and mixers employing a new open structure have been developed; signals from the HCN laser have been mixed together with a harmonic of a 70-GigaHertz klystron.

Millimeter Wave Propagation

Millimeter wave propagation research—theoretical and experimental—involves the interaction of millimeter waves with the lower atmosphere for telecommunications and remote sensing.

Measurements of noise emission from Colorado thunderstorm cells at 10.7 and 4.9 GigaHertz were made and analyzed to obtain an estimate of the line integral of liquid water content of storms. Atmospheric emission and solar radiation near 15, 31, and 53 GigaHertz were measured in Colorado and Hawaii for use in attenuation studies. The 53-GigaHertz data were also used for inferring temperature profiles in the atmosphere, using numerical integration techniques developed from theory for this purpose.

During FY 69, theoretical and experimental work continued in WPL to improve the radiometric technique for obtaining refraction corrections for missile-tracking systems. Preliminary studies, supported by the National Environmental Satellite Center (NESC), were carried out to determine the spectral intervals that could be used to measure surface conditions and vertical profiles of temperature, humidity, precipitable water, and water content of clouds from satellites. Closed effects on the various sensing techniques were emphasized.

Radio Meteorology

Studies on the interaction of microwave and lower radio frequencies with the lower atmosphere to facilitate radio telecommunications and to develop new remote sensing techniques continued during the past 2 years. Under study were atmospheric turbulence and structure and their relations to electromagnetic propagation and atmospheric dynamics.

A direct technique for determining evaporation with a microwave refractometer and sonic anemometer was developed in WPL. This instrument was used to assist the Department of the Interior's Bureau of Reclamation in measuring the effectiveness of monomolecular layers in reducing evaporation from reservoirs. A parallel development was made of an optical/microwave instrument to measure atmospheric water vapor remotely over paths more than 10 kilometers long.

The program of investigating interference fields by monitoring very high frequency (VHF) and UHF broadcasts was continued. Fine-scale atmospheric structure and concurrent synoptic weather over radio paths were measured.

Meteorological Doppler Radar

Studies of atmospheric phenomena by means of microwave pulse Doppler radar techniques capable of sensing the motion of atmospheric targets were underway. Particular emphasis in research conducted by WPL was placed upon detailed studies of severe convective storm dynamics (by simultaneous use of two or three Doppler radars observing the same storm from different locations), of mesoscale particle motion field in widespread storms, and of atmospheric turbulence.

The design and fabrication of the first two mobile X-band Doppler radar were completed, and fabrication of a third has been started. The dual radar system was used in studies of wind field dynamics in the low levels of convective storms and in the study of wind field patterns, associated convergence, and vorticity inside stratified storms as related to the precipitation mechanism.

Other studies conducted included observations made of the wind field inside snowstorms in Boulder, space and time variability of particle motion inside several convective storms, experimental forest fire kinematics, and feasibility of using "chaff" dipoles to study clear air motion. Signal processing methods, based on the use of a digital computer programmed with fast Fourier transform algorithms, were also developed during the reporting period.

Geoacoustics Research

Research involving theoretical studies and experimental measurements was conducted on the generation and propagation of infrasonic waves through the atmosphere and on the interaction between infrasonic waves and other geophysical phenomena. Results of such WPL research are used as a basis for deducing certain fundamental physical properties of the atmosphere, earth, and oceans.

Two new infrasonics stations were completed at Palmer, Alaska, and at Pullman, Wash., bringing the total number to seven stations operating in North America, South America, and the Middle East. Each station records the waveforms of sound waves that range in oscillation periods from 1 to 1,000 seconds; from these waveforms, the strength, azimuth of propagation, and horizontal trace velocity are determined.

In addition to infrasonic equipment, the Washington, D.C., station includes a 4-element array of short-period vertical seismometers, permitting direct comparison of Rayleigh waves with the infrasound they generate.

Observations of various geophysical sources were continued. The June 1968 explosion of the Caldera on Isla Fernandina in the Galapagos Islands produced readily measurable infrasound at North and South American infrasonic stations. Record waveforms are still being studied to evaluate the propagation of infrasound in the atmosphere.

AERONOMY AND UPPER ATMOSPHERE

In upper atmosphere research, basic knowledge is sought about the physical principles governing the formation and behavior of the ionized portions of the earth's environment and its relations to other parts of the environment. The subjects of study include programs in molecular and atomic collision processes in the atmosphere, ionospheric conditions peculiar to the area of the magnetic equator, airglow and aurora activity, geomagnetic behavior of the upper atmosphere, meteorology of the upper stratosphere, and propagation of radio waves in ionized media of all types.

Research and Development Programs

The bulk of the research programs are conducted by the RL's Aeronomy Laboratory (AL) [meteorology of the upper atmosphere is conducted by the RL's Air Resources Laboratories (ARL)], and involve primarily the prediction and control of those portions of the environment required to fill the telecommunications and space needs.

Laboratory Plasma Physics

Research in laboratory and theoretical plasma physics was conducted and applied to plasma problems peculiar to studies of geophysical phenomena. Emphasis in this AL research program was placed on those aspects of plasma physics that are not adequate understood.

Research on the theory of wave scattering, correlation functions, and nonlinear processes, including turbulence and transport coefficients, was undertaken. This research related diffusion to laboratory measurements of the correlation of density fluctuations.

A new turbulence theory based on plasma physics rather than neutral gas physics was developed during FY 69; this theory offered considerable promise for predicting the effects of ionospheric turbulence on the propagation of radio and radar waves. Such turbulence can enhance radio communications on earth by scatter propagation or can degrade communications with space vehicles.

Atmospheric Collision Processes

Both experimental and theoretical basic research on atomic and molecular processes, pertinent to the earth's atmosphere, continued in AL during the past 2 years with the development and application of techniques for measuring ionospheric ion-neutral reactions. The atmospheric D-region negative ion-reaction studies were extended, leading to predictions that NO_3^- would be a dominant ion. Temperature dependences of ionospheric rate constants were measured from 80° to 600° Kelvin. Atmospheric reactions of the metal ions—Fe^+, Mg^+, Ca^+, Na^+, K^+—and of Si^+ have also been measured; a scheme of E-region metal ion chemistry was developed and applied to the problem of ionospheric sporadic-E layers. The first laboratory measurement of an ion with an electronically excited neutral was also accomplished.

Broad studies of ionospheric positive and negative ion-neutral reactions continued during FY 69. The reaction scheme which produces the major D-region positive ions, $H_5O_2^+$ and H_3O^+, below 80-kilometer altitude was discovered; these reactions are now included in models of positive ion D-region chemistry. Water cluster ions are produced in sequences commencing with O_4^+ production. These and other studies conducted with this unique laboratory technique have developed strong evidence that the observed water cluster ions in the high atmosphere cannot be entirely explained as rocket contamination, an important implication for understanding the chemistry of the ionospheric D-region.

Rocket and Satellite Studies

Rockets and satellites were used in AL research investigations on the ionosphere and exosphere. The aim of these probes was to extend knowledge of the composition and dynamics of both of those spheres, of the plasma phenomena, and of such other processes as the interactions between rockets and satellites and the ionospheric and exospheric plasma.

Among the research results derived during the reporting period were: A method that obtains very precise values from topside sounder data for electron density and temperature; a new theory that explains radio frequency resonances as delayed echoes; an atomic oxygen detector that is based on thin film detection techniques; and a theory for probes that takes into account the effects of electric charge on the satellite. Preparations of several rocket payloads for investigating polar cap absorption events were also undertaken.

Studies of the dynamics of the topside ionosphere under disturbed conditions were undertaken; theoretical studies of the properties of radio frequency resonances observed in the ionosphere were continued; and a digital display system, complete with buffer and interface, to aid in the analy-

sis of topside ionosphere and other satellite data was fabricated.

The newly developed atomic oxygen detector was flown and additional techniques will be developed for detecting other minor atmospheric constituents. Rocket flights into a polar cap absorption event were conducted to determine the physical processes causing this phenomenon and to determine electron density loss processes.

Scatter Radar Studies

Incoherent scatter and other observing techniques were used in studies of aeronomy and plasma physics of the equatorial ionosphere conducted at the Jicamarca Scatter Radar Observatory near Lima, Peru.

By employing a refinement of the Thomson scatter-observing technique, a technique was developed by AL scientists for direct measurements of vertical drifts of the ionosphere. The monitoring of these drifts constituted a breakthrough, in that the east-west electric field propelling these drifts can now be studied continuously from the ground instead of through brief rocket observations obtained only during twilight hours; drift measurements are directly interpretable as electric field measurements.

Comparisons with simultaneous satellite measurements of electron temperature revealed some remarkable discrepancies. The satellite Langmuir probe results indicated temperatures about twice as large as those measured by the incoherent scatter technique. Measurements of neutral temperature, made at Jicamarca, also provided details of diurnal and solar-activity variation of F-region neutral temperatures that differed from satellite results; additional evidence has indicated that the incoherent scatter results are reliable.

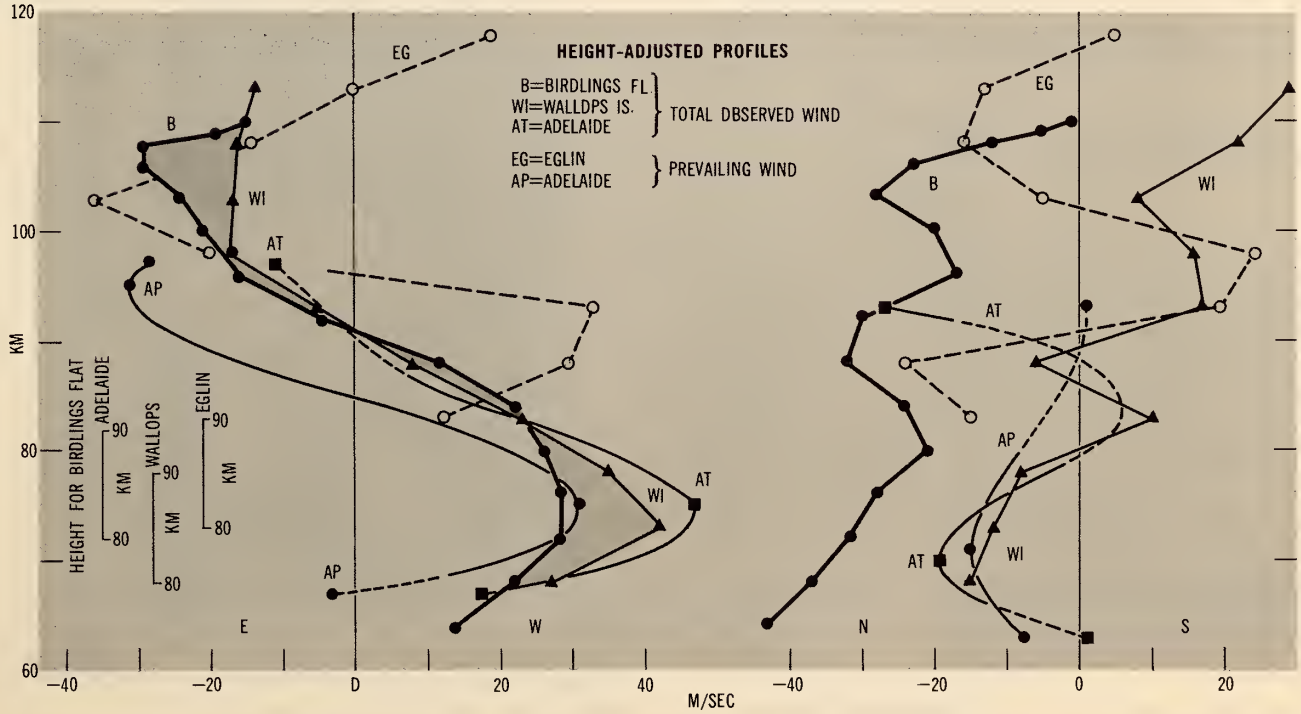
During FY 69, the AL conducted studies to detect minute changes in the direction of the geomagnetic field. Measurements of the lunar albedo were made, along with systematic monitoring of electron density and temperature and of ion temperature and composition.

Meteorology of the Upper Stratosphere

Ionospheric drifts and their relationship to the motion of neutral air were studied by a scientist from the ARL, based on measurements taken from Birdlings Flat, New Zealand, during the reporting period. The partial reflection method used at Birdlings Flat supplied data at 4-kilometer intervals within the 64- to 108-kilometer height range; these data were compared with meteor wind measurements, chemical release trails, and general circulation models.

Of special interest to ARL scientists were analyses of individual ionospheric drift profiles. From velocity curves separated by short-time intervals (40 to 115 minutes), various features attributed to gravity wave motions could be inferred. A train of gravity waves was assumed to exist in the 80- to 110-kilometer region, with the vertical wavelength of 12 kilometers and a period of 1 to 2 hours. When this model was interpreted in terms of changes observed in drift profiles, the results indeed suggested the presence of gravity waves. The vertical wavelength implied by ionospheric data was 10 to 12 kilometers, while the period could be either 80 to 150 minutes or 46 to 77 minutes.

Results of this ARL study were consistent with the wind interpretation of drifts. In seasonal averages, the motions implied by ionospheric drifts closely resemble movements of the neutral air.



Comparson of ionospheric drifts from Birdlings Flat, New Zealand, with neutral wind measurements at various sites for winter 1964 (curve B) and for miscellaneous winter periods.

Optical Aeronomy

Observations and interpretation of optical wavelength emissions from the upper atmosphere and interplanetary space were included in the AL research program during the past 2 years. The AL conducted specific studies of polar cap auroras by means of scanning spectrophotometers at McMurdo Sound, Antarctica, and aboard a National Aeronautics and Space Administration (NASA) aircraft in the Northern Hemisphere. The same instrument was used to observe emissions at twilight. These studies yielded valuable data relating to global atmospheric dynamics.

Studies of stable red arcs and observations of sodium dayglow and twilight continued. Auroral radar was used to investigate variation of aspect sensitivities with azimuth and with rates of growth and decay of reflecting centers.

SPACE ENVIRONMENT

The major effort in space environment research is placed on studies conducted by the RL's Space Disturbances Laboratory (SDL) of solar activity and its influence on terrestrial events. The study of solar flares is particularly important because these flares often eject proton streams which affect radio-reflecting characteristics of the ionosphere in polar regions and auroral activity. Telecommunications, supersonic transport (SST) flights, and men and machines in space can also be seriously affected by these events.

The SDL monitors and predicts fluctuations and disturbances in the earth's space environment associated with solar activity, and interactions with the lower atmosphere. These disturbances have important implications to man's utilization of the upper atmosphere and space.

The Space Disturbance Forecast Center (SDFC) at Boulder provides a forecasting and warning service for solar flares and proton events which affect the Nation's telecommunications, electrical power transmissions, and space flight activities.

Solar observing station at the Space Disturbance Forecast Center, Boulder, Colo., for observing the sun in white light and selected narrow spectral regions.

Research and Development Programs

Research programs on solar activity are essential for making possible more accurate forecasts of radiation hazards in space and the upper atmosphere and for determining the effect of radiation on telecommunication systems. Research is also aimed at understanding the space disturbances and their originating mechanisms, and at increasing the reliability and accuracy in monitoring and forecasting space weather.

Solar Energetic Particles

Physical mechanisms governing the energetic-particle environment were investigated during the reporting period, with particular emphasis placed on the precipitation of particles into the atmosphere and their consequent ionospheric effects. Models of ionosphere responses were developed for D-region electron loss processes. Measurement of the temperature coefficient for the major F-region ion-loss mechanisms was also made.

Rocket-sounding techniques were investigated by SDL for use in direct measurement of parameters of the energetic-particle flux and of the disturbed ionosphere. During FY 68, four photometric payloads were flown from Fort Churchill, Canada, on SKUA rockets.

Research during FY 68 indicated that midday recoveries during polar cap absorption events probably resulted from a change of pitch angle distribution of the bombarding solar cosmic rays.

During FY 69, the northern end of a conjugate auroral radar experiment was operated from Anchorage, Alaska, and very high frequency (VHF) ionospheric absorption/emission experiment was conducted at College, Alaska.

Magnetosphere

Theoretical and observational methods were employed by SDL to study the interaction of constantly streaming solar plasma with the geomagnetic cavity; mechanisms and magnitude of energy transfer through the magnetopause; time-dependent behavior of flare-generated shock waves; and plasma-wave generation and propagation in the transition region and magnetopause. Data from the chain of riometer-observing sites being operated by the Space Disturbances Monitoring Facility of SDL were used to define geomagnetic field topology and geomagnetic cutoff energies at high latitudes.

Studies of auroral absorption events, their global movements, conjugate properties, and relationship to phenomena observed in space by satellites were directed toward explaining the properties and behavior of auroral particle precipitation.

A description of the steady-state plasma flow field between the earth's bow shock wave and the magnetosphere boundary was given. The magnetosphere boundary location was verified, using observations from the Pioneer 7 satellite.

Theoretical simultaneous flow directions in the magnetosheath were verified by Vela observations. With regard to the influence of the geomagnetic tail on the precipitation of solar protons, the calculated magnetic cutoff latitudes agreed with observations to a higher degree of accuracy than any previously estimated.

During FY 69, several theoretical models of magnetospheric plasma flow were tested by incorporating solutions of hypersonic flow of a continuum gas past a blunted obstacle which represented the magnetosphere. Both steady-state and time-dependent solutions were examined.

Auroral precipitation studies were continued, with immediate attention focused on conjugate properties—specifically on displacement of conjugate points from their computed positions—and on hemispheric differences in the intensity of the particle precipitation.

Disturbed Ionosphere

Short-term (less than hourly) changes in the electron density structure of the atmosphere and in the incidence of solar X-rays and extreme ultraviolet radiation on the earth's atmosphere were investigated using radio wave techniques. In FY 68, investigations showed that during certain flares much of the enhanced ionization above the 100-kilometer level is produced by solar extreme-ultraviolet rather than X-radiation.

Acoustic waves—those waves with a frequency greater than the natural frequency of oscillation of the atmosphere—with periods that range from 20 seconds to about 5 minutes were observed in the F-region, having originated from nuclear explosions, severe weather fronts, and unknown sources.

Continuous observations of traveling disturbances in the Antarctic ionosphere have been made since December 1967.

During FY 69, SDL conducted research on solar flare spectra, comparing the spectra deduced from the ionosphere with those observed by satellite-borne sensors. A study of acoustic waves generated by severe weather systems and their propagation characteristics was also made, and analyses of Antarctic records were continued.

Investigations into the excited states of the oxygen atom, characteristic of regions from 100- to 400-kilometers, were conducted during the past 2 years with optical observations accomplished from the ground and from rockets. Problems involved in these investigations were also studied theoretically to determine the measurements of most importance and to examine the detailed effects of these excited states on the chemistry of the atmosphere. Current efforts are directed toward obtaining a height profile of excited O_2. Four photometric rockets were fired during the reporting period to obtain the excited oxygen profile in the upper atmosphere.

A study of the ionosphere and exosphere electron content, using radio beacon data from the eccentric Orbiting Geophysical Observatory (OGO) satellites, continued: the objective of this study was to present an integrated review of all observations and their interpretations.

Solar Physics

Rapid presentation of concise and informative flare data was improved through comparison of flare, sunspot, and plage observations gathered from different solar observatories. Relatively large horizontal motions of small elements have been seen in the undisturbed chromosphere, but these motions are dominated by less frequent but larger elements and movements in active regions. This observation, the result of a preliminary SDL study of high-resolution solar films in area, time, and wavelength, identified new areas for research in solar activity.

Considerable progress has been made toward perfecting ground-based radio techniques for the study and regular observation of irregularities in solar wind. These irregularities, moving radially outward from the sun at some 300 kilometers per second, cause scintillation (or "twinkling") of certain small-diameter flare-associated radio sources.

Work on a rapid-response one-dimensional radioheliograph continued. Tests were performed with an electronic correlator to synthesize 48 simultaneous fan beams in a narrow section centered on the sun. This device will eventually permit the accurate location of flare-associated radio bursts.

Synoptic Geophysical Measurements

Research conducted jointly by SDL with DOD's Advanced Research Projects Agency (ARPA) for the purpose of developing advanced methods to detect effects of high-altitude nuclear detonations was completed during FY 69. The observational portion of this research program involved the simultaneous recording on digital magnetic tape of the output of approximately 20 geophysical sensors. These sensors provided data on the ionosphere (including very low frequency (VLF), low frequency (LF), and high frequency (HF) signals propagating over various paths), geomagnetic field, solar noise intensity, infrasonic signals, and atmospherics from thunderstorm activity. An on-line computer was used to process the data before recording and to provide automatic detection of sudden ionospheric disturbances (SID) for use in the SDFC. Data were retrieved from magnetic tapes by microfilm plotting; processing was applied to the data before they were plotted. Multisensor data were used to investigate: (1) relationship between the various sensor responses following such distant occurrences as nuclear explosions, strong auroral activities, and volcano eruptions; (2) possible connection between tornadoes and certain types of changes in ionospheric propagation; (3) correlation between distant severe storms and arrival statistics of atmospherics signals; and (4) ionospheric changes which occur during SIDs and how they relate to solar X-ray emission. The efficiency of this computerized system to detect SIDs was found to be very good when compared to the conventional techniques which use reports from a large number of independent observing stations. The SDL also developed methods to indicate indices of activity for the ionosphere, geomagnetic field, and thunderstorms in real-time.

Forecast Techniques

Forecasting techniques research by SDL centered on the development of objective forecast formulas by statistical analyses and the use of numerical methods for electronic computers. During the reporting period, methods to verify many of the forecasts prepared by the SDFC were perfected. Several alternative methods of scoring the forecasts are now in use; verifications occur on a regular basis.

Instrumentation and Data Services

The Instrumentation Group of SDL provides general support to the Laboratory through the design and construction of special-purpose instrumentation; the Group also undertakes related work at the request of other ESSA components and Government agency groups. During FY 68, the Group maintained the instrumentation used by the SDFC in Boulder and had a special responsibility for planning and organizing data acquisition from satellites, for supporting ARPA-funded programs with geophysical sensors and interface equipment for the on-line computation system at the Table Mountain Electromagnetic Reception Site near Boulder, and for designing and constructing sounding-rocket instrumentation to measure polar cap absorption phenomena at high latitude in support of the Ionosphere Response Project. Noteworthy individual projects completed in FY 69 included an automatic system for measuring ionosphere total electron content by means of the Faraday rotation of radio signals received from geostationary satellites, and new sounding-rocket photometer instrumentation.

Geophysical data were collected, reduced, and analyzed for the SDL during the past 2 years. These data taken in Antarctica, Canada, Iceland, and Alaska were digitally recorded in most cases. A network of geophysical sensors was set up throughout Alaska to provide real-time input to a digital computer at the Anchorage Space Disturbances Monitoring Facility. The computer automatically alerts the SDFC whenever significant geophysical events occur; in addition, the computer sends detailed digital data to Boulder daily for scientific analysis.

Space Disturbances Forecast Services

During FY 68, the Global Solar Flare Patrol Network was completed. A small computer was installed in the SDFC at Boulder to interface with the Anchorage Space Disturbances Monitoring Facility computer which automatically handles the analysis and transmission of solar activity data and warnings. The installation of the optical telescope has improved the quality and quantity of the Boulder solar monitoring. Solar flare forecasts and warnings are distributed nationally and internationally by station WWV and VHF radio transmissions, from World Meteorological Organization (WMO) terminals, and through foreign regional warning centers.

8 ENVIRONMENTAL SATELLITE SERVICES

Service Programs

The National Environmental Satellite Center (NESC), one of the five Major Line Components (MLC) of ESSA, has the responsibility for the operation of the National Operational Meteorological Satellite System (NOMSS). In addition, the Center coordinates all satellite activities within ESSA and maintains liaison with other Government agencies having requirements for satellite data. In operating NOMSS, NESC performs the following functions: Commands and controls satellites in orbit, acquires and processes data from satellites, arranges for dissemination of both processed and unprocessed data, and works with the Environmental Data Service (EDS) to maintain an archival system for making data available for research. The Office of Systems Engineering maintains and improves current ground and data handling systems, plans for future spacecraft systems, and coordinates with the National Aeronautics and Space Administration (NASA) in the development of new and improved sensor and spacecraft systems. Systems Engineering also works with NASA on the procurement of spacecraft, launch vehicles, and launch services. The NESC also conducts research and development (R&D) in two areas: (1) the analysis and application of satellite data, and (2) the development of sensor systems for use on or with spacecraft.

The ultimate goal of ESSA in the Environmental Satellite Services is to furnish observations of the earth and its surrounding environment, consistent with the specific agency service responsibilities of ESSA, and to meet requirements of other Government agencies. Partial observations of the earth's surface, its oceans, and its atmosphere, and some observations of the flux of solar protons and X-rays have been obtained by satellite-borne instruments.

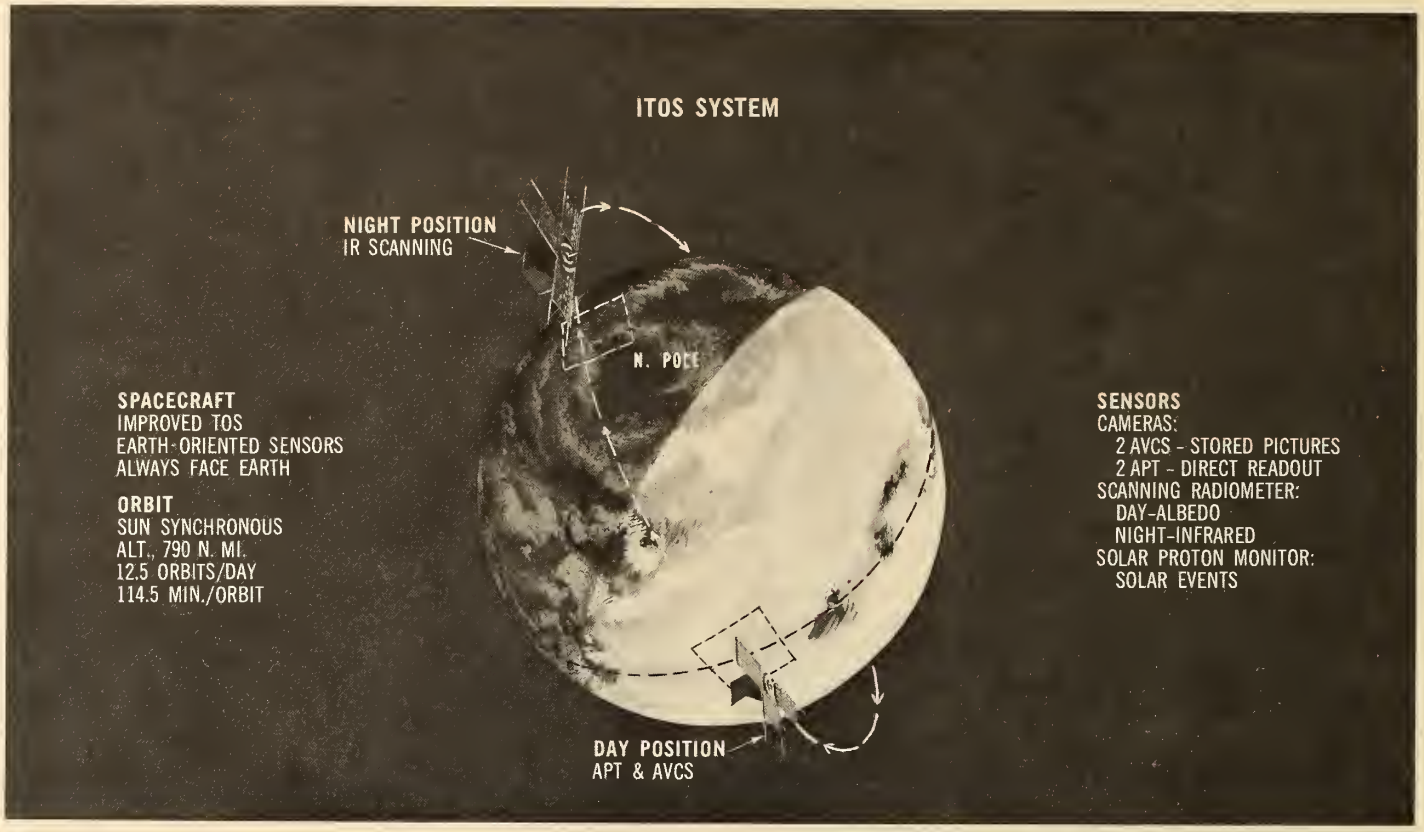
Spacecraft Systems

Two types of spacecraft are to be employed in the total environmental satellite observations system: polar-orbiting spacecraft and geostationary spacecraft.

During the period of this report, only one environmental satellite system, the TIROS (Television Infrared Observation Satellite) Operational Satellite (TOS) System, has been in operational use. This TOS System uses Environmental Survey Satellite (ESSA) spacecraft in near-polar sun-synchronous orbits to provide global cloud cover photography on the daylight portion of each orbit. The TOS System uses two types of ESSA spacecraft: One type provides global coverage by storing groups of pictures for later transmission to an ESSA Command and Data Acquisition (CDA) Station for central processing; the other takes and immediately transmits pictures to ground stations within range of the spacecraft by means of the Automatic Picture Transmission (APT) System. The APT ground stations are much less complex and less costly than the CDA stations and are owned and operated by U.S. and foreign meteorological services, and by individuals.

The TOS System is scheduled to be replaced by a second-generation operational system employing a single spacecraft, the Improved TIROS Operational Satellite (ITOS). A single ITOS spacecraft combines the functions of the two types of ESSA spacecraft in the TOS System. Each ITOS satellite carries both storage-type and APT cameras for daytime viewing and a scanning radiometer system which can acquire data in the infrared range on both the daylight and night portions of the orbit and in the visible range on the day side of the orbit. The ITOS spacecraft also will carry a solar proton monitor whose data will supplement other data used in the prediction of geomagnetic storms and of other phenomena that affect high frequency (HF) radio communications. Other sensor systems now under development will be added to the ITOS spacecraft as they are tested and proved operational.

The geostationary Applications Technology Satellites (ATS) 1 and 3, launched under a NASA R&D program, carry spin-scan cloud cameras capable of viewing a large disk of the earth at relatively frequent (15- to 30-minute) intervals. These Satellites orbit the earth at an altitude of 22,300 statute miles. With the spacecraft above the Equator, the orbit speed is synchronous with the rotation of the earth, hence the spacecraft appears stationary above a



Pertinent statistics on the Improved TIROS Operational Satellite (ITOS) System.

point on the Equator. A number of successful experiments, including real-time operational application, have been conducted with the camera data from these Satellites. Results of the experiments clearly demonstrate the utility of a geostationary environmental observatory.

Authority has been granted to proceed with the development of the Geostationary Operational Environmental Satellite (GOES) System which will permit nearly continuous monitoring of environmental conditions within view of the spacecraft. The launch of a NASA-developed GOES prototype, the Synchronous Meteorological Satellite (SMS), is planned for mid-1972.

Data Processing and Dissemination

The NESC maintains a data processing and analysis capability within its Data Processing and Analysis Division to process satellite data in real-time for daily operational use. For several years, satellite cloud pictures have been processed routinely by computer for operational use. The picture signals are digitized, rectified, and combined into mosaics for regular transmission by facsimile to U.S. weather stations. The mosaics are also transmitted experimentally, but rather routinely, to Europe, Asia, Australia, Oceania, and North and South America by means of transmitters on ATS–1 and ATS–3.

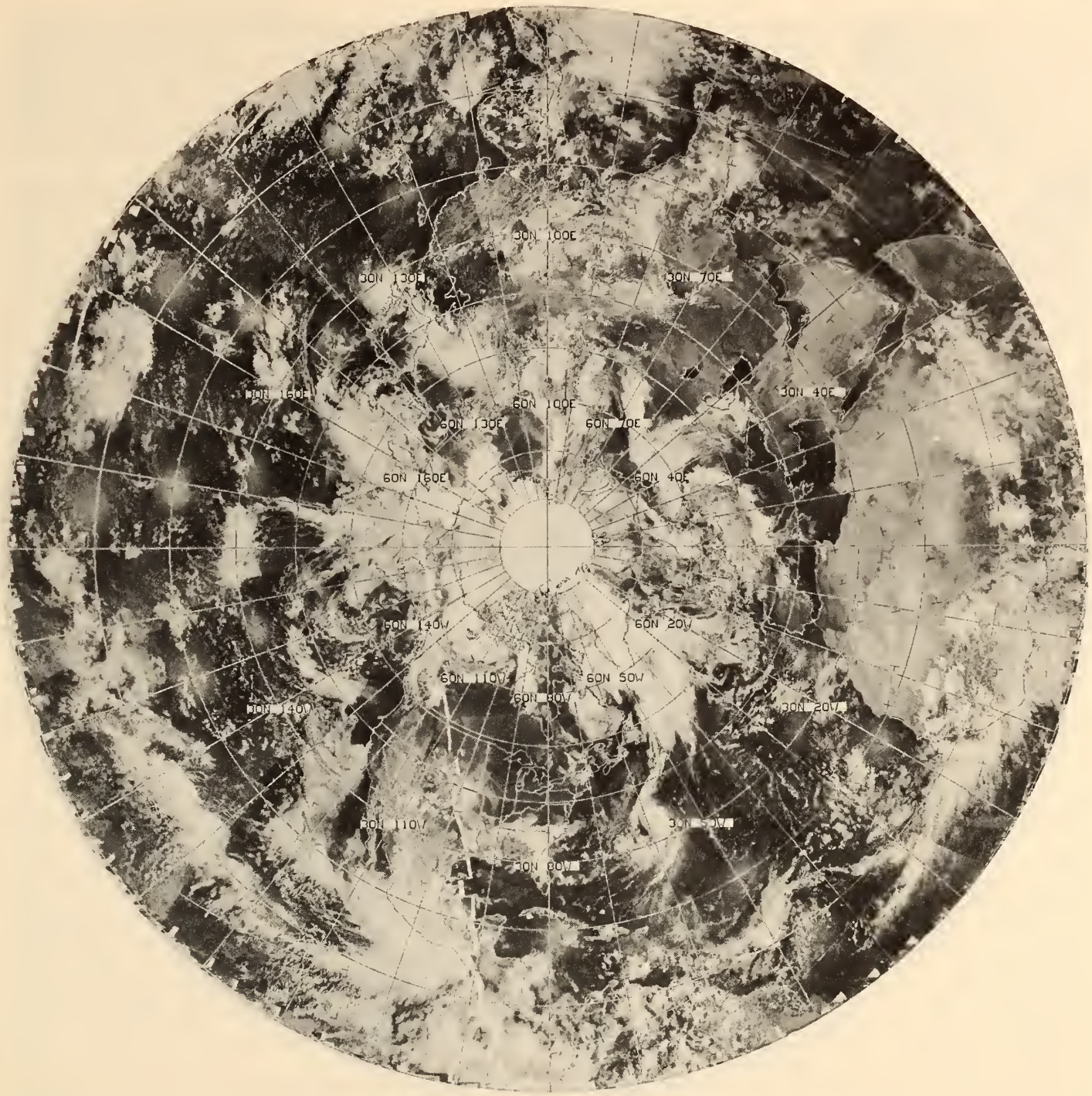
During the past year, additional computerized products have been developed. These include averaged brightness charts which represent the average cloudiness over an area for the time period involved. Five-, 10-, 30-, and 90-day (seasonal) averages have been produced; hopefully these will become the basis for up-to-date global cloud climatology charts. Charts of minimum brightness for 5-day periods show the extent of snow and ice fields, except in those areas where clouds have persisted for the entire period. Brightness charts comparing successive 5-day periods show areas nearly covered by snow or areas of recent snowmelt.

The APT pictures received at the Wallops Island, Va., CDA Station and at the San Francisco, Calif., Weather Bureau Forecast Office (WBFO) have computer-generated grids added to the pictures that are sent out to Weather Bureau Offices (WBO) on the Forecast Office Facsimile (FOFAX) weather network. This procedure saves manual gridding of the pictures at FOFAX-receiving stations within the conterminous United States.

The data processed for operational use are later deposited in archives from which they can be retrieved easily for research use. Data catalogs in the Key to Meteorological Records Documentation (KMRD) series are prepared on satellite cloud photography. As infrared data become available operationally, they too will be cataloged and made available through the National Weather Records Center (NWRC) maintained by ESSA at Asheville, N.C.

Operational Applications of Satellite Data

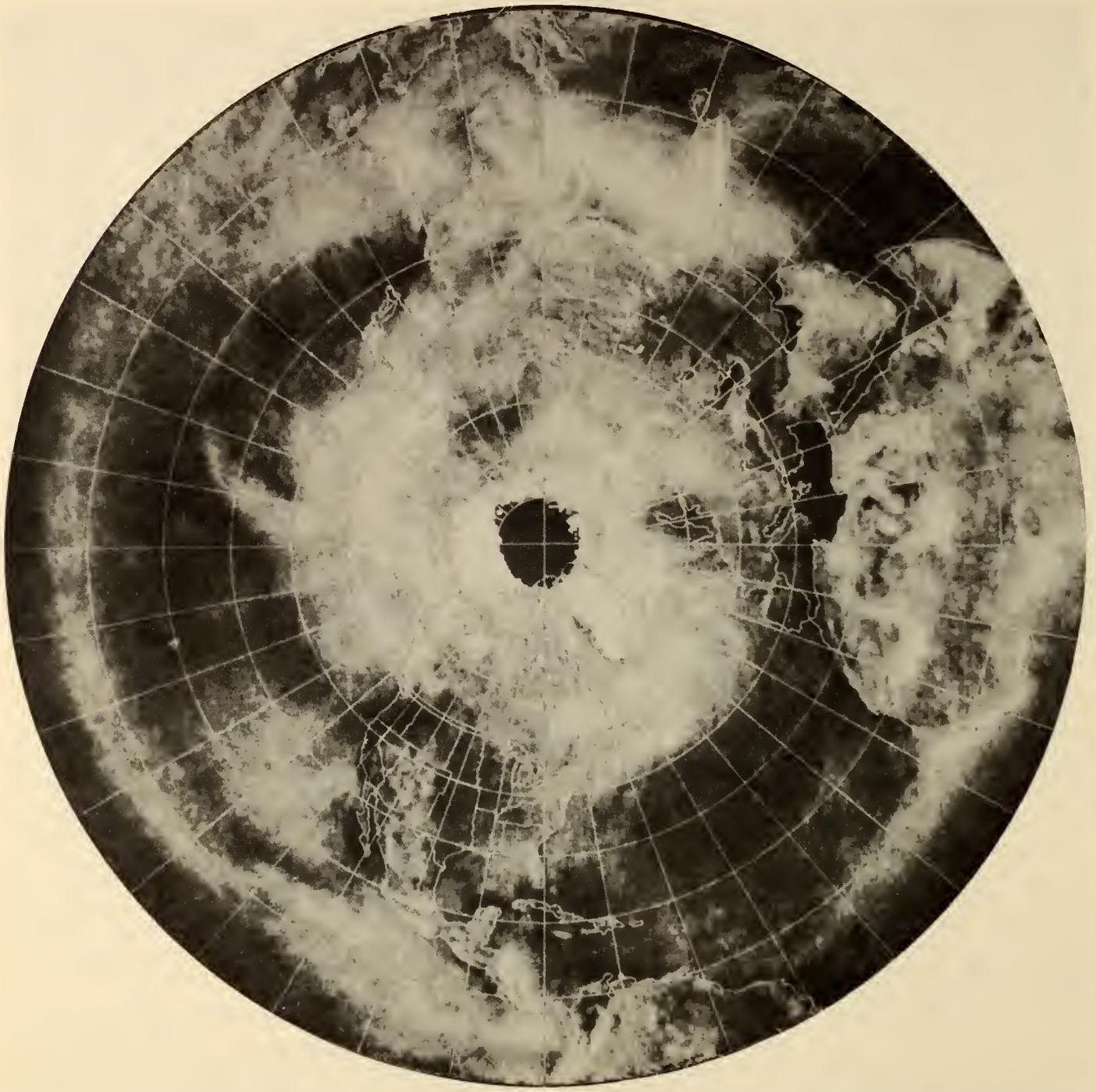
The operational satellite system has furnished cloud data routinely and reliably since February 1966. Daily operational usage of satellite data is widespread both in the United States and abroad. Digitized mosaics and hand-pre-



Digitized mosaic map of cloud cover in the Northern Hemisphere produced from ESSA 9 spacecraft photographs for August 21, 1969.

pared nephanalyses of worldwide cloud conditions are produced centrally in the United States and transmitted to many locations around the world.

Meteorologists found the satellite photographs particularly useful for discovering the tracking weather systems over approximately 80 percent of the earth where ground-based observations are not available. The discovery and tracking of hurricanes and typhoons from their inception to final breakup are the most spectacular use of this capability. During the past 2 years, more than 100 tropical cyclones, including Atlantic hurricanes, eastern North Pacific tropical storms or hurricanes, western North Pacific typhoons, and tropical cyclones of the Indian Ocean were spotted and tracked with satellite pictures. A technique developed by NESC provided the means for making relatively accurate estimates of the maximum wind speeds within a storm by direct examination of the satellite picture. Advisories on these storms were sent to U.S. installations and



Digitized 30-day average brightness mosaic map of the Northern Hemisphere produced from ESSA 9 spacecraft daily mosaics for July 13—August 11, 1969, to determine monthly average cloud cover.

foreign meteorological services worldwide. Storm tracking in the middle and high latitudes is used to provide improved advisory service, particularly to coastal areas, to aviation, and to ocean shipping interests.

Cloud-picture mosaics, prepared from either stored pictures or APT pictures or APT pictures received locally, were also used to decrease the use of aircraft for tropical storm reconnaissance, to reduce the time and cost for accomplishing photomapping of remote areas, and to eliminate the need for keeping a costly weather-observing ship on station between New Zealand and Antarctica. Picture mosaics were also used to produce weekly maps of ice conditions in the Great Lakes, the inland waterways, and coastal areas of North America, the Arctic, and the Antarctic. These maps are used by shipping interests in these areas and are particularly useful for routing ships on Antarctic resupply missions.

Winds at the 30,000- to 40,000-foot level, estimated from ESSA photographs, are used routinely in computer analyses and are transmitted daily to users worldwide. These estimates provide wind information over tropical and subtropical areas that are almost completely devoid of conventional upper level wind information.

Research and Development Programs

The research programs of the NESC include two general program elements: Studies designed to extract the maximum possible amount of useful information from satellite observations, and studies designed to determine the kinds of observations possible from satellites. In the first program, studies lead to an increased understanding of atmospheric processes, and to the development of methods for using satellite data in daily operations to improve analyses and forecasting of weather and other environmental features. The second program of study leads to the conceptualization and development of new instrumentation for measuring environmental data from a satellite platform.

Applications of Satellite Data to Environmental Analysis and Prediction

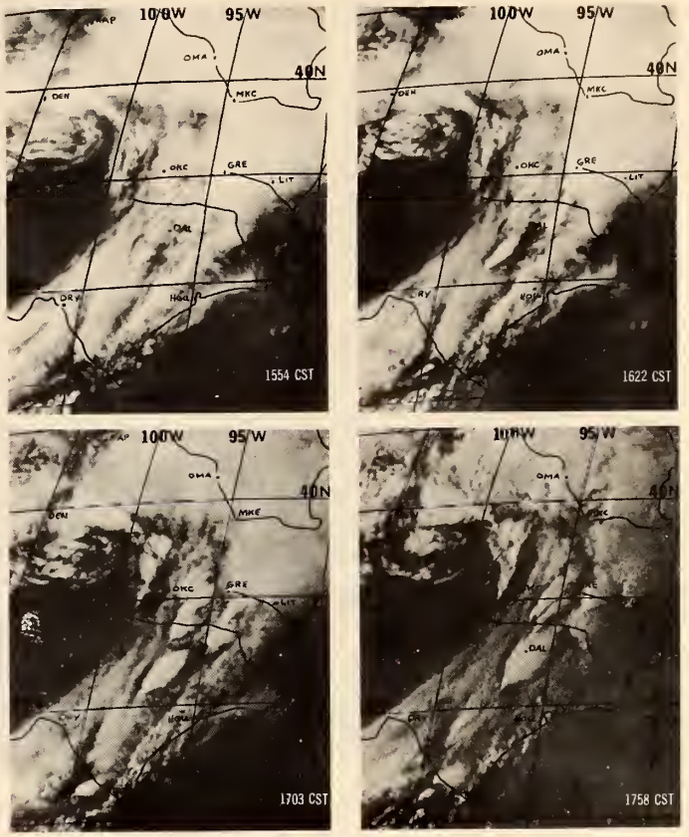
In this general program, research is directed toward devising methods for abstracting as much information as possible from satellite data, and toward developing methods for using these data in meteorological, hydrological, and oceanographic analysis. Because the data have been predominantly meteorological, emphasis thus far has been on atmospheric applications.

The picture data have been used to determine atmospheric conditions, synoptic patterns, and snow and ice conditions and to follow the movement of storm systems and weather patterns. The pictures also are used as a basis for estimating quantitatively the winds near the earth's surface and high in the atmosphere. Cloud pictures also are being used in the development of an objective method for deriving constant pressure heights for use with numerical analysis and prediction models of the atmosphere.

Picture data are used to study the development of both midlatitude severe storms and tropical cyclones and weather patterns. Mesoscale patterns of cumulus activity and cloud patterns influenced by the presence of mountains are also under study.

Radiation data are used in studies of the dynamics and energy patterns of general atmospheric circulation for the depiction of ground and sea-surface temperature distribution, cloud top topography, and ocean current location. Near the end of FY 69, the availability of Satellite Infrared Spectrometer (SIRS) data led to intensive and successful work on the development of methods to relate those data to atmospheric temperature profiles. Methods were also developed to use the SIRS data to construct constant-pressure surface contours and to integrate the data into numerical analysis programs.

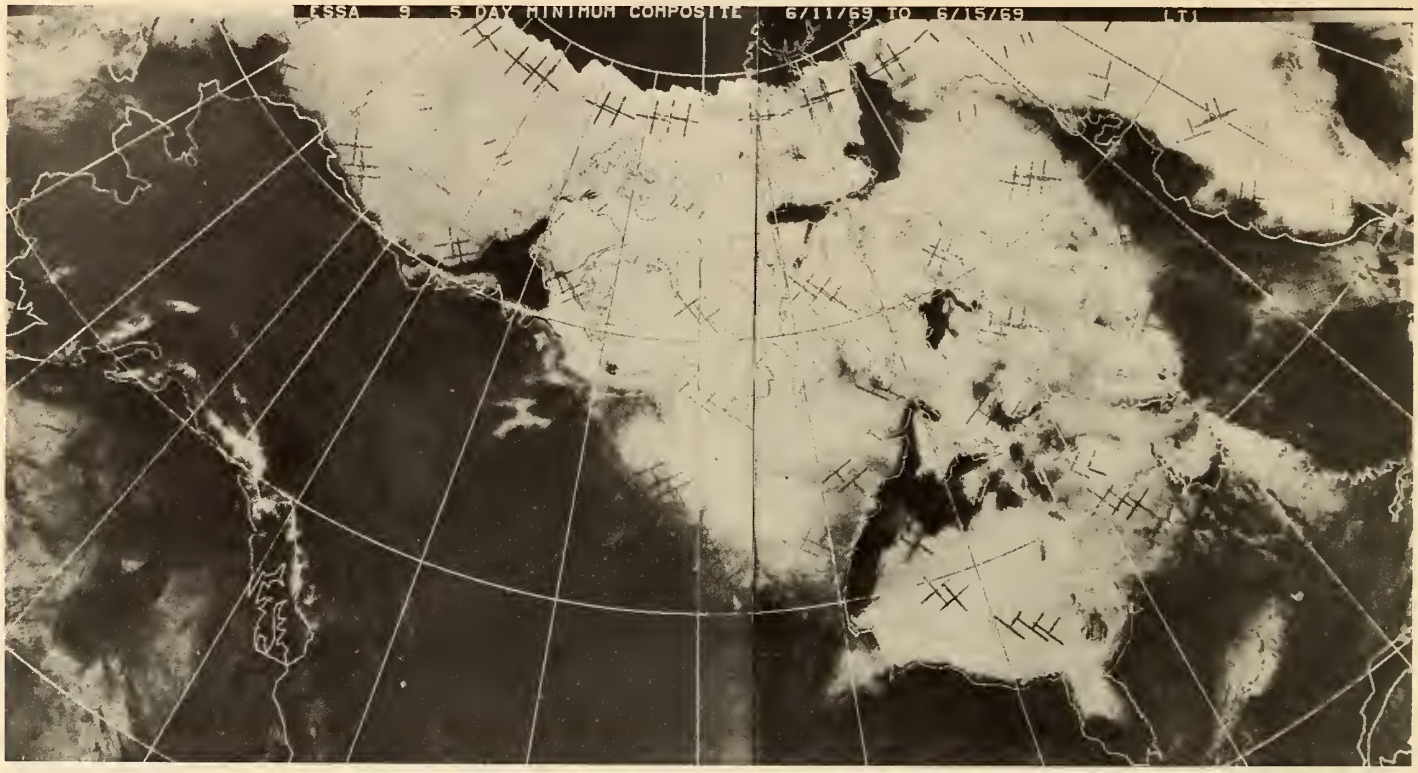
The near-continuous observational capability of the spin-scan cloud cameras of the ATS spacecraft has been used in a number of operational experiments. Procedures for



Growth of severe thunderstorms in a Midwest tornado situation as shown in photographs taken from the synchronous ATS-3 spacecraft on April 19, 1968.

making time-lapse motion picture film from ATS–1 and ATS–3 photographs have been greatly refined in the past 2 years. It is now possible to study the conditions in a hurricane within 1 or 2 hours after the pictures are taken, and to use the information for making forecast decisions on the motion and intensity of the storm. Pictures taken at 15-minute intervals by ATS–3 were used in 1969 for the first time in a real-time operational experiment for forecasting the movement of a hurricane. At first, the storm appeared to threaten the gulf coast, but daily examinations of the pictures contributed toward an early and definite forecast of an "all clear" for the coastal area. A substantial saving probably resulted because it was not necessary to issue warnings to evacuate coastal areas and to protect property from hurricane winds and tides. The ATS picture films are also used daily to estimate high- and middle-level winds over the entire Pacific Basin. The wind estimates are used as data input to the objective analysis programs processed by high-speed computers.

Data from the still active ATS–1 and ATS–3 spacecraft are being used for operational experiments in storm tracking and forecasting. Experimental forecasting of east coast snowstorms, using ATS–3 pictures as a unique data source, is planned for the late winter season of FY 70, and will continue during the winter season of FY 71. The ATS pictures will also be used experimentally during the 1970 tornado and hurricane seasons by the Severe Local Storms



Digitized 5-day average minimum brightness mosaic map of Alaska, Canada, and Greenland produced from ESSA 9 spacecraft daily mosaics for June 11—15, 1969, to show the extent of snow cover.

(SELS) Unit of the National Severe Storms Forecast Center (NSSFC) at Kansas City, Mo., and by the National Hurricane Center (NHC) at Miami, Fla. These Centers will receive ATS–3 pictures by means of a real-time photofacsimile relay from the NESC's CDA Wallops Island, Va., Station.

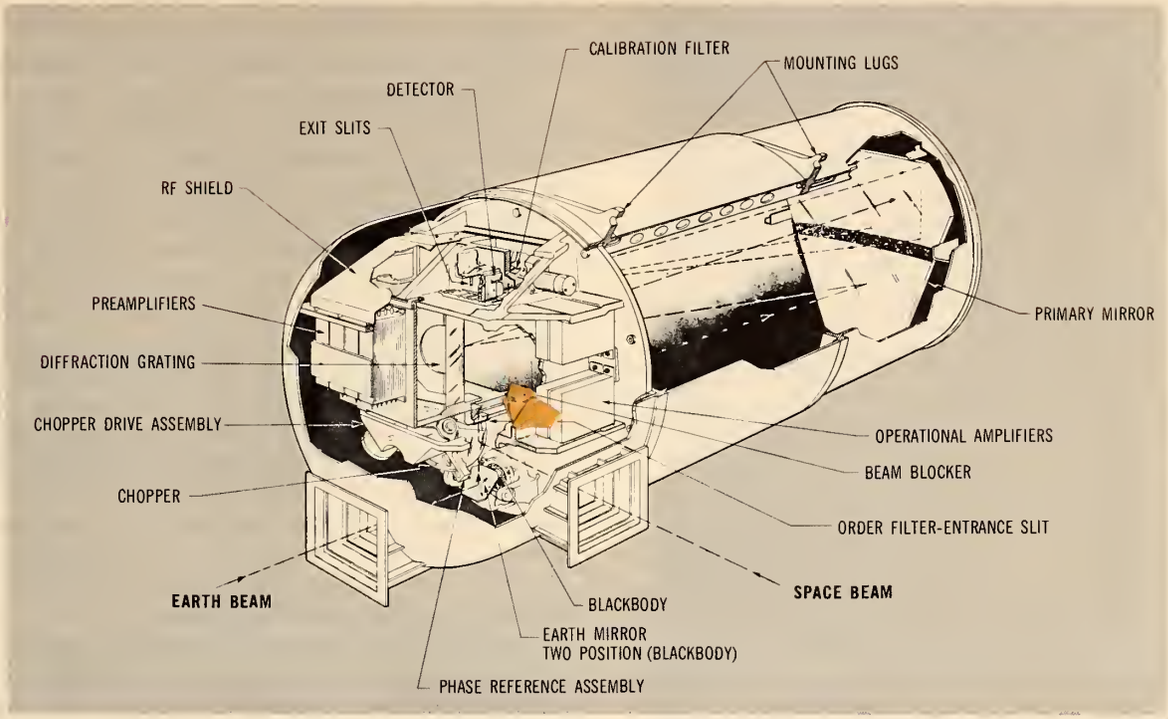
In hydrology, techniques were developed that permitted the use of satellite pictures for mapping snow cover and ice fields in lakes, rivers, and the open ocean. Prior research has established that the edges of snow fields can be located with a reasonable degree of accuracy. Current research is directed toward finding ways to determine the depth of snow cover and toward improving location accuracy. Estimates of snow cover, based on computer-processed satellite picture data, assisted hydrologists in making accurate forecasts of the flooding potential over the North Central and Rocky Mountain States in the spring of 1969.

Radiation data were available from the Nimbus 3 satellite from two sets of instruments. The 5-channel Medium Resolution Infrared Radiometer (MRIR) and the single-channel High Resolution Infrared Radiometer (HRIR) provide information by scanning across the path of the satellite as the satellite moves in orbit; SIRS provides information by sensing radiant flux originating at various levels in the atmosphere.

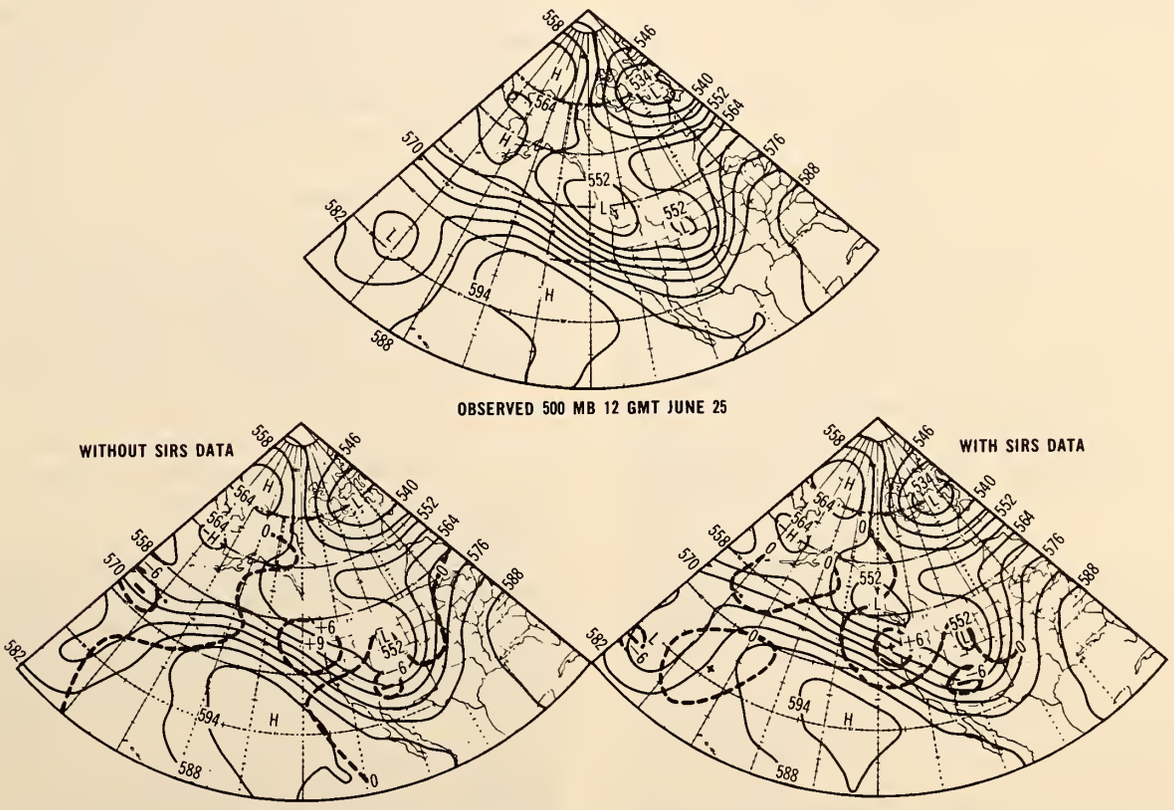
The MRIR data, with a resolution of about 30 nautical miles, provide information for mapping the horizontal distribution of moisture at upper levels and, at lower levels, the albedo (reflected sunlight), stratospheric temperature, and cloud top and surface temperatures. The HRIR instrument senses surface and cloud top temperatures at a much finer resolution (about 5 nautical miles) than does the MRIR instrument.

The radiant flux from various levels in the atmosphere is sensed by the SIRS. This instrument, which had been under development for 10 years, performed spectacularly well; it provided temperature soundings within hours after the April 14, 1969, launch of Nimbus 3. The SIRS instrument measures infrared radiation from various levels in the atmosphere. These measurements are converted by mathematical processing to vertical temperature profiles (soundings) of the atmosphere. Seven measurement channels provide data for the sounding; the eighth channel provides measurements of the temperature of cloud tops or, in cloud-free areas, the temperature at the surface of the earth.

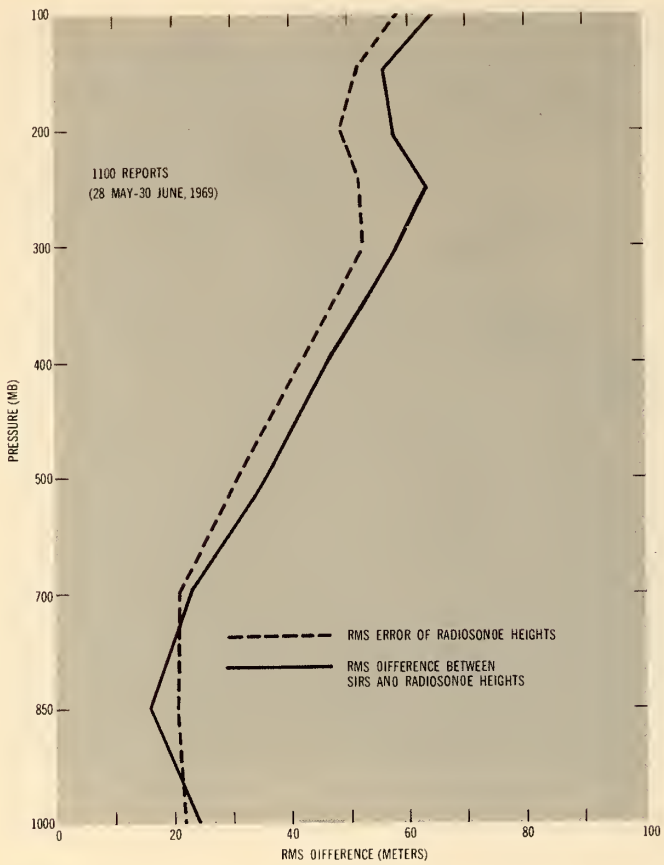
Since the first SIRS measurements were obtained, a steady stream of measurements, equivalent to some 8,000 to 10,000 atmospheric soundings over the globe, have been received every 24 hours. For practical considerations, only 400 soundings are computed daily for operational use in the Northern Hemisphere numerical weather analysis; additional soundings over the Southern Hemisphere are computed for later use in research programs. The Northern Hemisphere soundings derived from SIRS radiance measurements have been used in daily operations since June 1969 in the Weather Bureau's (WB) numerical upper air analyses for 1200 GMT (Greenwich Mean Time). Experimental comparison forecasts, starting with 500-millibar analyses without and with SIRS data, have shown that the addition of SIRS data has, at least in the cases studied,



The SIRS instrument designed to measure the vertical temperature profile of the earth's atmosphere from satellite altitudes.



Forecast 500-millibar patterns for June 25 (12 GMT), with and without the use of SIRS data, compared with the observed pattern.



Root mean square error and difference comparisons of SIRS- and radiosonde-derived geopotential heights.

resulted in significant improvement in forecasting some major features of the midtropospheric flow.

Oceanographic research using satellite picture data and infrared data separately or in combination was started in 1968. The specular reflection patterns of the sun on the ocean surface are being analyzed as a means for determining surface wind speeds in remote areas. Basic methods have been developed for this determination; current work is directed toward the development of a computer program that will accomplish the necessary analysis in a time sufficiently short for operational use. Infrared data are used to map ocean-surface temperature fields and surface currents, such as the Gulf Stream, and to determine moisture patterns in the sea-air interaction layers of the atmosphere. Investigations are directed toward determining the possibility of using microwave sensors to provide some of the above data and to provide measurements on the temperature structure in the upper levels of the ocean. The information is expected to be useful both for oceanographic and meteorological purposes.

Design and Development of Satellite Sensors and Systems

The R&D under this general program in NESC is divided into three basic program elements: the design and development of specific instruments, the design and study of instrument components and materials, and the study and development of both concepts and techniques for observing various environmental parameters from satellites.

Instruments developed under the first program mentioned above include the very successful SIRS described earlier. The SIRS remote sensing technique for obtaining measurements of the vertical temperature profiles of the atmosphere is considered one of the major technical breakthroughs of the decade. An improved version of SIRS, designed to measure moisture and temperature, is being readied for flight on Nimbus D in 1970. Another instrument derived from the SIRS concept is being developed for flight testing on Nimbus E. This is the Infrared Temperature Profile Radiometer (ITPR), which will have spatial scan capability to improve operations over areas partly obscured by clouds. A spectrograph instrument to determine the height of cloud tops by measuring the absorption of reflected light in the oxygen "A" band continues under development. This spectrograph has been tested during aircraft flights, and the data show positive correlations between the measured absorption and the cloud top heights.

Materials and instrument components are studied and tested in support of the second continuing program to improve existing instruments and to develop new sensors. For example, diffuse reflector materials for on-board calibration of the visible channel of satellite radiometers are being identified, and a low temperature black-body radiator for use as an in-flight calibration standard is being studied.

Detailed studies are being conducted on the effects of the chemical and physical characteristics on the sensing of environment parameters from a space platform. These effect factors also affect the development of techniques to convert the sensed data to representative quantitative values. This third program includes studies on the optical properties of clouds and on the effect of atmospheric turbidity upon satellite sounding.

New techniques for obtaining observations are under investigation, for example the use of light detecting and ranging (Lidar) equipment to detect the type and amount of atmospheric aerosols present at a given time and to obtain measurements of the diffraction characteristics of clouds. Also under study is the use of microwave sensors to obtain measurements of surface temperatures through cloud decks, and of sea-surface conditions (sea state) in the absence of specular reflection patterns. Microwave sensing is also being studied for its possible use in obtaining atmospheric sounding data.

A satellite-interrogated buoy system was under development during the last 2 years. The system concept is to use instrumented buoys moored at deepwater stations. The data acquired by the instruments are to be transmitted to a satellite upon interrogation, and then relayed to an analysis center. The buoy was designed and two prototypes tested on location in the North Atlantic Ocean. Both tests successfully demonstrated the stability of the buoy and the durability of the mooring system. The Coast Guard assisted in mooring the buoy and maintained visual and radio checks on the buoy during each test period.

9 ENVIRONMENTAL DATA AND INFORMATION SERVICES

Service Programs

ESSA has a major responsibility for both research and dissemination of environmental data and information. The Environmental Data Service (EDS), a Major Line Component (MLC) of ESSA headquartered in Silver Spring, Md., maintains specialized data centers for meteorological, geodetic, seismological, geomagnetic, oceanographic, ionospheric, space disturbance, and other geophysical information. The Scientific Information and Documentation Division (SIDD), located at ESSA Headquarters in Rockville, Md., provides an informational retrieval and storage center for all research and development (R&D) projects underway in ESSA. During the reporting period, both organizations initiated R&D activities to improve their respective data centers.

Environmental Data Service

The EDS component of ESSA is responsible for the collection, quality control, storage, retrieval, display, and dissemination of worldwide geophysical data relating to the atmosphere, oceans, solid earth, and space. These data come from the MLCs of ESSA, other governmental agencies, and cooperating nations.

Climatological Data Service

EDS's Climatological Data Service programs include the collection, processing, analysis, interpretation, and dissemination of information concerning various climatic elements. Through increased understanding of climate and its effects upon aviation, agriculture, construction, transportation, commerce, health, and recreation, users of climatological data are able to make more effective decisions in their responsible field.

Climatological data are collected at EDS from four primary sources. The first source is the hourly reports of surface weather conditions received on a regular 24-hour basis from approximately 610 stations—310 from the Weather Bureau (WB) and 300 from the Federal Aviation Administration (FAA)—in a joint WB-FAA station network, plus U.S. military stations throughout the world. A second source is the data obtained from the WB's 205 upper air stations (134 furnish temperature, pressure, and humidity data; all furnish wind data). A third source is the data provided by about 12,000 volunteer precipitation-observing stations, of which approximately 5,000 forward daily temperature readings. Supplementary data are also collected from about 1,000 special-purpose agricultural and public service stations. The fourth source is data reported by the Reference Climatological Stations; about 17 of these Stations have been permanently located in environmentally stable regions with long histories of homogeneous observations and good prospects for future continuity.

Volunteer Observing Network

Daily readings of maximum and minimum temperature and precipitation are a minimum requirement to define the climate of a region. Such volunteer readings are obtained at present from a network of reporting stations, spaced approximately 25 miles apart, in selected locations throughout the Nation. Currently, about 5,000 cooperative stations constitute the basic climatological network. The reports of all 13,000 cooperative stations are sent by mail monthly to the National Weather Records Center (NWRC) at Asheville, N.C.

State Climatology

The EDS provides a special service geared to the climatological conditions of the individual State or region. The key individual is the State or Regional Climatologist who is an expert on the climate within his State or region of responsibility. His key task is to work with local and State organizations, frequently through the State universities or colleges, and to assist these organizations in the solutions to problems which have an impact on the State or local economy. As part of the State Climatologist's

service, he answers requests for climatological data. For example, he provides climatological data to engineers who need such data for use in the design and layout of buildings or to agricultural county agents who require growing condition data and other related information. Forty-four State Climatologists and six Regional Climatologists serve the 50 States and Puerto Rico.

National Weather Records Center

Among the functions performed by the NWRC are the routine collection, quality control, punching, verification, processing, analysis, publication, and final storage of U.S. climatic records. In addition, the Center prepares special nonroutine studies like the periodic summarization of climate and makes special studies for public and private agencies. The NWRC houses World Data Center A (WDC-A) for meteorology and nuclear radiation, under sponsorship of the National Academy of Sciences (NAS). The Center contributes to international climatological efforts by providing representation to working groups of various technical commissions, such as those engaged in maritime meteorology and climatology.

Operator handling microfilm spool of weather records within the "clean room" of the NWRC, Asheville, N.C.

Central Data Dissemination

For the benefit of public and scientific users, climatological information is available from EDS's Office of Data Information in Silver Spring, and from NWRC in Asheville. Dissemination of information occurs as maps, tabular record summaries, regular publications, letter supplements, and brochures.

Geophysical Data Centers

An important part of the data systems activity includes the Geophysical Data Centers—consisting of the Seismological Data Branch and Geodetic Data Branch of the National Geophysical Data Center in Asheville and the Geomagnetic Data Center in Rockville.

The Geodetic Data Branch collects, prints, archives, and disseminates final data pertaining to all geodetic station data processed by ESSA. Data for horizontal control stations consist of verbal descriptions of the station locations, azimuths, geographical positions, and plane coordinate positions. Data for vertical control stations include verbal descriptions of the central locations and station elevations. Index maps of control station locations are also available. As of the end of FY 69, approximately 185,000 geographic control positions (horizontal control stations) and 320,000 elevations (vertical control stations) were on file in the Geodetic Data Branch.

The Seismological Data Branch collects, films, archives, and disseminates final data from an international network of seismograph stations. Most data disseminated by this Branch consist of standardized seismogram copies. These seismograms are distributed to seismologists, other scientists, and engineers throughout the world. These data are invaluable research tools for determining estimates of earthquake magnitude, for improving accuracy of earthquake predictions, and for increasing knowledge of the earth's physical properties. As of the beginning of FY 70, approximately 1.5 million seismograms were on file in the Seismological Data Branch.

The Geomagnetic Data Center is one of four worldwide Data Centers for Geomagnetism (the other three are in Denmark, Japan, and the Soviet Union). Microfilm copies of daily magnetograms and processed data from approximately 185 world observatories are transmitted to one of these four Centers for archiving and for disseminating upon request. Through a mutual exchange program, each Data Center receives input for its data bank from the other three. Inputs from 15 ESSA observatories and approximately 50 observatories of other countries are sent initially to the Rockville Center. As of June 30, 1969, approximately 850,000 magnetograms were on file in the Geomagnetic Data Center.

Oceanographic Data Center

Oceanographic data—exclusive of geophysical, mapping, tidal, and tidal current data—are available to users through the National Oceanographic Data Center (NODC) in Wash-

Researching triangulation points on the North Carolina Triangulation Diagram at the Geophysical Data Branch of the National Geophysical Data Center, Asheville, N.C.

ington, D.C. This Center, the largest repository of oceanographic data in the world, was established in 1960 through the cooperative effort of various governmental agencies participating in the National Oceanographic Program to serve as a centralized oceanographic data bank. The Center is administered by the U.S. Naval Oceanographic Office. Ten agencies and bureaus—including ESSA—fund NODC, with the level of support from each based on data input. Policy and technical review functions are exercised by the 12-member NODC Advisory Board, composed of representatives from each supporting agency and bureau and two research community representatives appointed by the NAS. Data collected and analyzed from participating agencies and bureaus are assembled and stored at NODC for dissemination upon request.

Upper Atmosphere and Space Environment Data Center

Another of the data systems available to users is the Aeronomy and Space Data Center, funded by the EDS to collect upper atmosphere and space environment data essential for space environment and telecommunication predictions and to satisfy scientific research needs. On a regular and continuous schedule, this Center, located at the Research Laboratories (RL) Headquarters in Boulder, Colo., receives, exchanges, compiles, stores, and publishes final data to aid the geophysical disciplines.

The great majority of the upper atmosphere and space environment data are collected through continuing national and international agreements established during the 1957–58 International Geophysical Year (IGY). The Aeronomy

and Space Data Center manages and operates WDC-A for those scientific subjects. Data are exchanged regularly with World Data Center B (WDC-B) in the Soviet Union and with World Data Center C (WDC-C). Because WDC-C is comprised of four European countries—France, Italy, Sweden, and the United Kingdom—and Japan, exchanges are effected only with the country that has responsibility for a specific scientific subject. Data relating to the ionosphere, airglow, aurora, cosmic rays, solar activity, and aeronomy, received from observatories throughout the world and from upper atmosphere monitoring satellites, are involved in the exchanges.

Science Information

Science information activities include the collecting, processing, compiling, analyzing, indexing, storing, retrieving, publishing, and disseminating of scientific and technical information. Such activities involve most of the substantive work of the MLCs of ESSA—from the initial observations of land, sea, or atmospheric elements to the resultant forecasts or warnings based on the observations and on the understanding gained through research or theoretical studies.

All of these activities are covered in other chapters of this report. In this chapter, the narrower definition of science information implies collection, storage, and retrieval of published documents or their surrogates—such as abstracts, summaries, announcements, indexes, catalog cards, microforms, punched cards, and tapes.

The SIDD of the Office of Administration and Technical Services, ESSA, is charged with developing, maintaining, and performing the above systems or services, including libraries and publications, necessary to provide environmental scientific information developed in ESSA or elsewhere in the world to users in ESSA and other Government agencies or to the general public.

Research and Development Programs

The EDS conducts in-house studies and supports some R&D projects at selected universities and consultant firms. These various studies and projects deal first with the identtification and development of data retrieval and storage systems, and with the equipment needed for more rapid and efficient automatic processing and dissemination of present and future environmental data; in addition, investigations into applications of the data help develop methods of analysis which dictate how data shall be archived.

Special studies are conducted in support of the climatological services program of EDS, including the development of design data for use by various industrial users; analysis of records to facilitate the production of food more efficiently, to permit the design and operation of better engineering structures and processes, to aid in the preparation of better weather forecasts, and to determine the causes and processes of climatic change are also made. Many techniques are applicable to other data systems programs operated by ESSA.

Gridding Northern Hemisphere map data with a Large-Area Record Reader (LARR-V) at the NWRC, Asheville, N.C.

Data Systems Development

The NWRC processes a rapidly growing volume of weather observational data. Approximately 100 million U.S. and foreign meteorological observations are received annually, including climate, marine, upper air, synoptic, surface, and aviation observations. Work is in progress to design and construct equipment to transform these observational data into compact, pertinent formats to achieve rapid retrieval and maximum usage of data.

A preliminary 10-year plan for archiving climatological data has been prepared; as needs of other geophysical disciplines are determined, these disciplines will be integrated with climatology into an efficient, total geophysical data system. User needs will be subject to study to determine their data requirements and to encourage further exploitation of the records by all disciplines. A fast, cheap means of achieving automation, miniaturization, random access, and reproduction will occur gradually rather than as a single breakthrough.

The development of a Film-Optical Sensing Device (FOSDIC) was undertaken by the EDS Systems Design Group during the reporting period as a cooperative project with the National Bureau of Standards (NBS). This project involved the production of a third-generation electronic system for high-speed reading, editing, and conversion of microfilmed punched card data to digital magnetic tape. A small, commercially available, general-purpose computer and appropriate off-the-shelf peripheral equipment were used to design and construct a more reliable, easier-to-use system. The basic system was designed, and the film scan director and film handling units were constructed.

During the past 2 years, a new, improved electronic reader, incorporating off-the-shelf computer and tape-writing means, was under development. A high-resolution planetary camera with automatic feed was designed, built, and tested to determine further ways to improve low-cost, high-quality reduction of paper records to microfilm.

Another EDS study in data retrieval and storage systems involves environmental data formats. The objectives of this study at the University of Wyoming are to classify and interrelate the various kinds of environmental data, to fit the classification into an environmental data index, to postulate the optimum format and content for various kinds of environmental data, and to recommend the equipment and procedures required to implement an adequate Environmental Data Service. An analytical study of these geospheric operations from which environmental data are acquired has been undertaken. Investigators observed operations in EDS and other data banks. Definitions of the elements of the environmental data index were developed and methods for analysis of geospheric operations were described. A preliminary report on pictographic numerals for space-time coordinates has also been completed.

Synoptic Climatology

A major research effort in synoptic climatology by EDS's Laboratory for Environmental Data Research (LEDR) involved the development of computer methods to analyze Alaskan weather records from January 1945 through March 1963. Synoptic weather patterns from these records were identified and classified as a means to establish probabilities of weather systems occurrence in the Arctic. The monthly and annual variations of zonal and meridional indices, based on the heights and thicknesses at certain millibar levels, and temperature gradients (zonal and meridional) were investigated over Alaska. The predominance of the semiannual variations over certain sections of Alaska has been associated with general patterns of circulation over the northern part of the Pacific Ocean and with frequencies of low and high centers over Alaska (at the 700-millibar level).

As part of this research effort, several problems were under investigation, including the height and strength of the surface inversion; mean and variation of monthly 500-millibar height and 500/1,000-millibar thickness; height, pressure, and temperature at the tropopause over Alaska; and interdiurnal changes of these parameters. Additional facets of this project treated the Alaskan anticyclone, its influence on the surface conditions, and the influence of surface conditions upon the anticyclone, and investigated the preferred sites of cyclogenesis in the vicinity of Alaska and the reason for such development.

Investigations by LEDR into climatic conditions in Alaska focused on the mean weather conditions during occurrences of specific weather patterns over the State; namely, those patterns derived from the records for January 1, 1945, to March 31, 1963. Correlations were found between the changes of 500-millibar heights and 500/1,000-millibar thicknesses from month-to-month, and between mean monthly temperature gradients at 700-, 500-, 300-, and 100-millibar levels in meridional and zonal directions over Alaska. These correlations were evaluated and harmonic analysis methods were applied to annual variations of: (1) thicknesses at the 500- to 700-millibar, 300- to 500-millibar, and 100- to 300-millibar levels; (2) gradients of thicknesses in meridional and zonal directions; and (3) isobaric temperature gradients at the 700-, 500-, 300-, and 100-millibar levels.

Developing weather systems were studied to achieve possible feedback into weather forecasting techniques. These studies have expanded knowledge of expected operating conditions in Alaska for military personnel and equipment and for natural resources development of the State. As a basis for planning structures, transportation, and population support, a knowledge of weather patterns promises help.

Climatic Change

Supporting research in climatic change is aimed at a broad investigation into the overall problem of climatic change in the 20th century to meet long-range national planning goals. This research is concerned with: (1) difficulties of reliable measurement of climatic change; (2) statistical character and meteorological interpretation of climatic change; (3) causes of climatic change including

those related to man's activities; (4) predictability of future climate; and (5) impact of climatic change on man and environment. The approach has consisted basically of three elements. The first element is the analysis of extant historical climatic data to verify past climatic change and the establishment of new observational programs (notably the Reference Climatological Station Network Program) to document future change more adequately. The second involves study of the statistical nature and physical interpretation of climatic change through techniques of time-series analysis to determine the form of nonrandomness in climatic variability, gaining clues to its physical causes and predictability. The third element includes application of physical climatology theory and numerical modeling experiments of atmospheric circulation and climate to obtain a basic understanding of the physical mechanism, cause, and predictability of climatic variation.

Progress in research on climatic change is closely related to progress in knowledge of the general atmospheric circulation, to advances in numerical simulation and prediction of the atmosphere, and to improvements in the worldwide observational network for reporting meteorological and oceanographic conditions. Research gives new insights into meteorological consequences of such environmental disturbances as solar activity, lunar and solar tides, volcanic activity, sea-air interaction, and atmospheric pollution.

Climatic change research by LEDR focused on five distinct study areas. The first study area is expansion of the Reference Climatological Station Network to 17 stations, complete with new instrumentation for the measurement of resultant wind, and continued development of additional instrumentation to be made in the Network at a later time. The second area includes reprogramming the temperature homogeneity analysis used to verify the quality of historical climatic records, and extending this analysis to maximum and minimum temperatures separately on a pilot study basis in Maryland. The third involves preliminary updating of a worldwide index of long-term temperature change, initially calculated to 1960, which indicated a continued cooling of world climate during the past decade. The fourth centers on an evaluation of the role of global air pollution—carbon dioxide and atmospheric dust loading—in causing worldwide fluctuation of temperatures during the past century and in contributing to temperature trends anticipated for future decades of this century. The fifth and final study area comprises a continued study of climatic change in the geological and historical past, together with the various environmental disturbances in the past that may have caused such climatic change, to gain the necessary perspective on environmental forces that contribute to climatic changes at the present time. From the latter two study areas, it is becoming increasingly clear that the fluctuation of worldwide climate in the last century resulted primarily from natural causes of still unknown specific character. Human activities are capable, however, of causing global climatic change, and threaten to become a dominant cause of further climatic change in the future if industry and technology advance as anticipated.

An ancillary LEDR study at the University of Arizona's Laboratory of Tree-Ring Research concerns the application of historical tree-ring data in developing a detailed chronology of climatic conditions throughout the western portion of the North American continent during the past 500 years. The research approach required calibration of modern tree-ring series against concurrent meteorological data through an elaborate statistical analysis to isolate climatic factors, to obtain anomalous ring thicknesses for each tree species and for each physiographic setting, and to use this calibration to infer past climatic conditions from earlier tree-ring chronologies.

Research in the past 2 years has progressed to the stage where this method of indirect climatic reconstruction has produced highly realistic patterns of climate and atmospheric circulation over the western portion of the United States. The resultant patterns indicate periods of severe drought in the Southwest that correlate with archaeological evidence of agricultural and social upheavals in that region during those times. The main objective of this research is to supplement the relatively short meteorological history of the Nation by establishing the statistical probability of recurrences of persistent droughts and other extreme climatic anomalies of the kind that have occurred in recent decades.

A statistical analysis was made of historical tree-ring data and solar activity indices to determine the extent of a relationship between climate and long-term solar variability. A principal component analysis of ring variations at 26 different tree sites in western portions of North America and a cross-spectrum analysis between these components and sunspot numbers revealed only weak evidence for any such relationship.

It is expected that this particular research investigation will provide a better indication of the risk of extreme climatic anomalies in the future and will help detect causal factors in climatic change such as historical variations in solar activity.

Bioclimatology

One of the more important programs of EDS is bioclimatological research which has application in agriculture, health, and recreation. During the past 2 years, EDS, through its LEDR, conducted research to develop an understanding and quantitative characterization of those climatic aspects which impose limitations on the success and efficiency of agricultural program planning, food production, and water resources management. Much of this diversified program is conducted through contract-supported research at a number of universities; the aim is to create a better understanding of the basic relationships of evaporation, transpiration, wind shelter effects, precipitation, energy balance at the earth's surface, and corresponding responses in plants and animals. The internal EDS effort concentrates on methods for using this acquired knowledge to facilitate a uniform food supply, with minimum stress on the Nation's resources and at minimum eventual cost to the consumer.

A computer procedure was adapted to determine the

extent, severity, and duration of periods of unusually wet or dry weather. This procedure was applied to the historical record of weather and climate since 1930; drought severity has been calculated on a monthly basis for all areas of the United States and Puerto Rico. An additional procedure was developed using weekly temperature and precipitation observations to compute consistent week-to-week appraisals of crop moisture conditions throughout the United States and Puerto Rico. These results are published for the use of Government agencies and other groups having an interest in agriculture and business generally.

A consulting office—Agricultural Climatology Service Office (ACSO)—was established within the Department of Agriculture (DOA) to interpret meteorological information for agriculture problems. The ACSO can and does assist farmers with timely information. For instance, the annual influx of the screwworm into the Southwest is influenced by how far south into Mexico this agricultural pest was pushed by freezing winter temperatures and by how much summer moisture is available for its survival and spread. The sterile fly control program can be managed better if knowledge of temperature and soil moisture from winter through summer is available. Constant climatic surveillance along the United States-Mexican border ultimately will be a decisive factor in the eradication of this destructive animal parasite from all of North America.

This liaison office—ACSO—in the DOA was established to bring environmental data directly to the problem. Because applied climatology is necessarily interdisciplinary, the climatologist can use his data and methods of application in cooperation with engineers, pathologists, entomologists, or agronomists. This principle of interdisciplinary cooperation has proven practical; it will be employed in other EDS areas of application as resources and opportunities permit.

The EDS research in bioclimatology extends to work being accomplished in hydrology, agricultural meteorology, and extended forecasting in the WB. Further, the efforts of EDS contribute to international progress through commissions and working groups of the World Meteorological Organization (WMO), United Nations Educational, Scientific, and Cultural Organization (UNESCO), Food and Agriculture Organization (FAO), and others; these efforts are concerned with widespread drought, methods of assessing weather effects on plants and animals, ways of making management decisions in industry and economics, and means of providing pertinent data collection and dissemination.

During the past 2 years, EDS has completed a study on the operation of a mesoscale network of integrating pyranometers and made an analysis of radiation data obtained from pyranometers in Wisconsin. The study and analysis was conducted by the College of Agriculture at the University of Wisconsin. A known cosine-response diffusing head was modified to contain a silicon solar cell and to have adjustable output. From among several integrators, a suitable model for reliable all-weather operation was developed. Seventeen pyranometers were field-tested to note and correct deficiencies. The variability of radiation totals obtained is being studied for application to the design of future networks. Daily radiation measurements were started in December 1966, and are being continued through the winter of 1969-70. Except for occasional missing observations, errors of only one Langley per day appear to be most prevalent even during this experimental period of operation.

Texas A&M University, through LEDR, initiated a study to determine whether quantum efficiency for photosynthesis in higher plants is sufficiently constant with wavelength to justify its use as a rational physiological basis for a new system of light measurement; if proven constant, a single representative spectral absorptance curve could then be used to convert from radiant energy flux incident to quantum flux absorbed. This study involved the growing of a large number of food plants under controlled and natural conditions. At suitable intervals during the growth cycle of each plant, leaves were selected to measure the photosynthetic rate and spectral absorptance. To measure photosynthetic rate, the sample leaf was placed in an assimilation chamber and irradiated with monochromatic light; to measure absorptance, the leaf was placed in an integrating sphere and irradiated with the same light. The spectral quantum efficiency and the spectral absorptance were calculated from the results of these two sets of measurements. Final results, expected in mid-1970, will guide ESSA in measuring meaningful radiation quantities in the future.

Purdue University was awarded a LEDR-grant to initiate research on predictions of diurnal and seasonal temperatures at varying depths within soil profiles through a field and laboratory study in Indiana. The research approach involved estimating the depth at which the diurnal change (amplitude) in temperature is 12 hours out-of-phase with high noon and the depth at which diurnal variation approaches zero. Estimates of annual and seasonal soil temperature trends and lags at the depth where diurnal variation approaches zero were also made. Maintenance and calibration procedures for use of the Palmer Soil Thermometer were completed. Several soil temperature observational stations were established, and programming of several data analysis procedures was also accomplished. Results indicate that it may be possible to estimate long-term temperature distributions in time and depth of soil from a very short period of onsite observations, enabling action programs in new areas to progress quickly.

Another EDS project involved the collection and analysis of phenological data for the western portion of the United States to determine climatic relations and natural patterns of the environment in that portion of the country. The project was conducted by Montana State University. Plant genotypes were established, and dates of budding and flowering in relation to measured climate in more than 1,000 locations were then recorded. Observations from lilac plantings from 1957 through 1969 were computerized for irregularities. Mapping the geographical pattern of standard deviation of plant development in the Western United States denoted a maximum of variability in the Southwest. Multiple regression analysis of median flowering dates revealed some wide departures from Hopkins' Bioclimatic Law. The possibility of operating a uniform phenological network throughout most climatic zones of the conterminous

United States definitely exists. These observations can be important in interpretation of future earth resources data obtained through remote sensing procedures. Immediate uses include detection of insects and disease spread in terms of seasonal progress.

A growing degree-day study was contracted through LEDR to the Ohio Agricultural R&D Center. Research was initiated on the establishment of a standard method for determining "varietal constants" of corn hybrids in Ohio and the development of normal growing degree-day unit values for all areas within that State. This study involves utilization of several methods for determining heat or radiation units and then relating these units to "varietal constants" for corn. A modeling procedure is being employed to refine the relationship of accumulated heat units during the growing season with phenological events. Prospects for gaining acceptance of a standard growing degree-day system among major hybrid seed corn producers are excellent.

The University of Hawaii obtained a grant from the LEDR to conduct research into the energy budget of Hawaii. Measurements of solar radiation, surface albedo, radiation, and other environmental factors were made with Eppley Pyrheliometers, Monteith Solarimeters, a recording silicon photovoltaic solar cell, a Thornwaite Net Radiometer, and other instruments available locally. Influences of such various surfaces as asphalt, latosol, pineapple and sugarcane fields, buffalo grass sod, rain forests, and sand beaches were compared by albedo measurements. Much of the research effort was directed toward calibration and comparison of radiation instruments. Net radiation measurements at different elevations along the southern slope of Mauna Loa were also recorded. An empirical formula was derived to express net radiation as a function of incoming radiation, Angot's value, temperature, and humidity. Research was completed in FY 69.

As part of its program in bioclimatology, EDS conducted a study to measure evapotranspiration from a high production field crop in Missouri and to relate these measurements to environmental data. The University of Missouri fulfilled the research requirements for the study. A simple lysimeter and energy balance techniques were used to obtain estimates of total evapotranspiration in irrigated crops for period of several days. Good estimates of evapotranspiration were obtained over long time periods. A precision lysimeter has been installed to permit further evaluation of more specific causal factors in terms of daily water losses.

An EDS study to determine a reliable estimate of actual daily evaporation as a function of measurable soil waterflow characteristics, of a plant canopy characteristic, and of potential evapotranspiration was performed by the University of Wisconsin. Both the amount of water in the root zone and the rate of waterflow to the root system in a drying soil were deemed important to the estimate; the surface soil temperature and the nature of the plant canopy as a diffuse vapor source were also considered in estimating actual evapotranspiration in a given weather situation. Initial instrumentation was started.

Research for LEDR by the University of Nebraska, involving measurements of evapotranspiration and photosynthesis over short time periods to determine the simultaneous interactions of these two phenomena, was underway during the reporting period. Climatic and plant responses were recorded with a lysimeter and other meteorological instruments in a site with optimum fetch of airflow over the instrument location. Aerodynamic and energy balance estimates of evapotranspiration rates were compared. The instruments and recording equipment at the alfalfa crop site were placed and made operational. Analysis of data is in progress.

Mesoclimatology

The EDS research in mesoclimatology is concerned with investigations on how man is changing his environment in the mesoscale through industrialization, land clearing, air pollution, and urbanization, and on how this knowledge can be applied in the future. Effects of these research investigations are somewhat long range because they point out observational needs and provide avenues of approach to pollution problems. Determining what to measure and how to evaluate fluctuations in this measurement are basic to the conservation and improvement of the environment.

During the past 2 years, studies of the influence of soil radiative properties on station temperatures and research into the effects of urbanization on temperature were underway in LEDR. Temperature-measuring devices, suitable for use in vehicles, were purchased and deployed in Washington to measure air temperatures in that city.

Illumination measurements were also analyzed in a restricted portion of the Eastern United States. These illumination data and statistics are useful to assess remotely sensed radiometric data from meteorological satellites. Meteorological satellite data were also applied to cloud climatological analysis.

Long-period change in cloud cover over the Pacific Ocean was found to be related to change in the general atmospheric circulation and to variation in the temperature distribution of ocean water.

Three-Dimensional Global Climatology

Research into three-dimensional global climatology was performed at NWRC for LEDR and involved the determination of: (1) static structure of the atmosphere from the surface to as great a height as feasible; (2) dynamic structure of the atmosphere by spectral analysis to provide preferred modes of motion in the atmosphere in three dimensions—latitude, longitude, and altitude; and (3) various time scales indicated to be important by spectral analysis. Geophysical data were checked for accuracy and comparability and were summarized statistically in atlases and statistical tables.

These studies contribute significantly to the design and building of equipment and structures exposed to environmental stresses—for example, rockets, launching facilities, supersonic aircraft, and marine equipment. Plans by EDS for a three-dimensional boundary layer climatology in the mesoscale for each major urban area in the United States were made. Such data would afford design criteria for in-

dustrial development which would be capable of preventing serious degradation by the atmospheric environment. This planned climatology involved the National Environmental Satellite Center (NESC) and the National Aeronautics and Space Administration (NASA) with the Department of Health, Education, and Welfare's (DHEW) National Air Pollution Control Control Administration (in cooperation with the Air Resources Laboratories' (ARL) Cincinnati, Ohio, facility) and with individual Weather Bureau Offices (WBO) having knowledge of local data sources and their peculiarities.

Statistical Climatology

The program of EDS in statistical climatology focused on the development of statistical methods for climatological analyses to understand the role of the weather factor and its application to design, planning, and decision problems.

One of the statistical climatology research projects initiated by EDS involved the cooperation of the NBS on the design of an experiment to relate micrometeorological wind observations to pressures on a building. The approach to this project was to make extremely detailed observations of velocity and pressure over the face of the building and to develop methods for their potential analysis. New methods of extreme value statistical theory have been developed for application to the calculation of design snow loads, wind loads, and ocean wave heights. Probability theory was also developed to obtain tornado design data for power lines and nuclear reactors. Statistics on storm and tornado damage to buildings and on mortality rates were studied to explain trends.

The NWRC initiated a 6-year project with EDS during the reporting period involving research on ways to prepare a global atlas of clear air turbulence (CAT). This project involves the collection of background literature on CAT; development of ideas and concepts for global presentation; collection of CAT data; and preparation of local, geographical, regional, continental, marine, hemispheric, and global presentations.

Aeronomy and Space Data

The Aeronomy and Space Data Center in Boulder, funded by EDS, conducts research into aeronomy and space data systems with the objective of developing improved methods for collection, standardization, archiving, retrieval, and publication of such upper atmosphere geophysics data as aurora, airglow, cosmic rays, ionosphere, and solar activity. Research by the Center is sponsored by the NAS program for WDC-A, and involves the Steering Committee of the International Ursigram and World Days Service (IUWDS). Investigations are underway on the development of systematic methods to implement decisions of the various international scientific unions concerning coordination and implementation of international data interchange.

Scientific Information Development

The principal developmental effort of SIDD since the formation of ESSA in July 1965 has been the long-range development of a science information system to include the three major ESSA libraries—Atmospheric Sciences Library (ASL), Geophysical Sciences Library (GSL), and Boulder Laboratories Library (BLL)—and serve all of ESSA's research laboratories and centers; major regional or State operational centers and public service offices; and ultimately, ESSA's hundreds of individual field stations, units, or survey ships.

In November 1967, the Scientific Information and Documentation Council of ESSA adopted a policy definition of an ESSA Library System as a network of libraries and collections of published technical information and data among ESSA elements throughout the 50 States.

Basic to the effectiveness of the System is coordinated interaction, within and between libraries and collections of different types, guided by the Libraries Branch of SIDD. Interlinking of the major scientific libraries, large specialized collections at research centers and laboratories, and regional libraries would be aided by the availability of appropriate computer-stored inventories of holdings in the constituent libraries.

The Council also directed SIDD to develop a plan for an overall ESSA Environmental Science Information System, including the ESSA Library System. During the reporting period, a number of steps were taken toward that goal.

In 1968, a survey of the ASL and GSL in the metropolitan Washington area was made by consultants from the University of Maryland Library School. The resulting report has served SIDD as a general guide for possible priorities in its long-range development of the ESSA Library System as a component of an ESSA Environmental Science Information System.

A sampling consisting of 3,000 oceanographic holdings from the catalogs of ESSA's three major libraries—ASL, GSL, and BLL—was put into machineable form by a contractor, and listings were made by a number of different methods—that is, by library (chronologically); author and title; corporate author; contract, grant, or project number; subject heading; Universal Decimal Classification (UDC) class number (form, place, language, and subject); and keyword-in-context (KWIC). Multiple copies of the computer printout of the listings were reproduced in four volumes and sent to such potential users as libraries and laboratories for feedback and suggestions.

Several applications of computer manipulation and printout of records and direct tape-typewriter reproduction involving ESSA publications, announcements, research-in-progress reports, and vocabularies were under development.

A plan for a comprehensive ESSA Environmental Science Information System was developed for implementation by the Scientific Information Systems Branch of SIDD. This plan recommends the integration of various types of environmental science information into a common system accessible to users of all types in laboratories, field stations, or offices, and eventually by high-speed communications facilities where available.

The System is to be tailored for the special users of information from the disciplines of environmental science, but can be integrated with national and international systems and other specialized systems such as university or educational networks in peripheral and core fields of interest.

Conventional forms of dissemination will be byproducts for retrospective usage or for dissemination to users not having direct access to on-line facilities.

During FY 69, SIDD assumed responsibility for the ESSA Research and Technology Information System, giving recognition to the importance of documenting current research in progress, in addition to publishing results of past research in the ESSA Environmental Science Information System. The research resumes are used for program review and scientific information purposes, both within ESSA and as part of a Government-wide research data bank.

Because of its parallel responsibility for the storage, retrieval, and dissemination of environmental science information in raw or tabulated form, EDS has made or contracted studies during the reporting period on the overall data and information indexing problem to acquire better access to the billions of data bits accumulated in both machineable and potentially machineable form.

The studies have attacked two problems under the concept of "Endex": (1) the *overall data access* problem where thousands of special types of data are involved; and (2) the *terminology* or *classification* problem for description and recall of specific data by subject, time period, and place. These problems involve an interface between raw data in machineable or nonmachineable form and published or summarized data supplementing the raw data, or vice versa, depending on the purpose for which the data are required.

GLOSSARY OF ACRONYMS

ACSO	Agricultural Climatology Service Office
ADP	Automatic data processing
ADTECH	Administration and Technical Services, Office of
AEC	Atomic Energy Commission
AFO	Agricultural Forecast Office
AL	Aeronomy Laboratory
AMOS	Automatic Meteorological Observing Station
AMVER	Automated Merchant Vessel Reporting
AOL	Atlantic Oceanographic Laboratories
APCL	Atmospheric Physics and Chemistry Laboratory
APT	Automatic Picture Transmission
ARATOL	Air Resources Atmospheric Turbulence and Diffusion Laboratory
ARL	Air Resources Laboratories
ARPA	Advanced Research Projects Agency
ARS	Agricultural Research Service
ASL	Atmospheric Sciences Library
ASO	Agricultural Service Office
ATEX	Atlantic Trade Wind Experiment
ATS	Applications Technology Satellite
AWS	Agricultural Weather Services
BLIP	Boundary Layer Instrument Package
BLL	Boulder Laboratories Library
BOMAP	Barbados Oceanographic and Meteorological Analysis Project
BOMEX	Barbados Oceanographic and Meteorological Experiment
CARF	Central Airspace Reservation Facility
CAT	Clear air turbulence
CDA	Command and Data Acquisition
C&GS	Coast and Geodetic Survey
COSMOS	Coast Survey Marine Observation System
DACAN	Data Acquisition and Analysis
DASA	Defense Atomic Support Agency
DHEW	Department of Health, Education, and Welfare
DOA	Department of Agriculture
DOC	Department of Commerce
DOD	Department of Defense
DOT	Department of Transportation
ECCRO	Eastern Caribbean Cooperative Reconnaissance Operations
EDL	Equipment Development Laboratory
EDS	Environmental Data Service
EML	Earthquake Mechanism Laboratory
EMSU	Environmental Meteorological Support Units
ETAC	Environmental Technical Applications Center
ESG	Environmental Sciences Group
ESL	Earth Sciences Laboratories
ESSA	Environmental Science Services Administration
ESSA	Environmental Survey Satellite
FAA	Federal Aviation Administration
FAO	Food and Agriculture Organization
FCST	Federal Council on Science and Technology
FOFAX	Forecast Office Facsimile
FOSDIC	Film-Optical Sensing Device
FSS	Flight Service Stations
GARP	Global Atmospheric Research Program
GFDL	Geophysical Fluid Dynamics Laboratory
GMD	Ground-based Meteorological Detector
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellite
GSL	Geophysical Sciences Library
HF	High frequency
HRIR	High Resolution Infrared Radiometer
HUD	Housing and Urban Development, Department of
IAGA	International Association of Geomagnetism and Aeronomy
ICAO	International Civil Aviation Organization
IER	Institutes for Environmental Research
IFR	Instrument Flight Rules
IGOSS	Integrated Global Ocean Station System
IGRF	International Geomagnetic Reference Field
IGY	International Geophysical Year
ITC	Intertropical Convergence Zone
ITL	Ionospheric Telecommunications Laboratory
ITOS	Improved TIROS Operational Satellite
ITPR	Infrared Temperature Profile Radiometer
ITS	Institute for Telecommunication Sciences
ITU	International Telecommunications Union
IUWDS	International Ursigram and World Days Service

JORG	Joint Oceanographic Research Group
KMRD	Key to Meteorological Records Documentation
KWIC	Keyword-in-context
LASA	Large Aperture Seismic Array
LEDR	Laboratory for Environmental Data Research
LF	Low frequency
Lidar	Light detecting and ranging
Loran	Long-range aid to navigation
MIT	Massachusetts Institute of Technology
MLC	Major Line Component
MRIR	Medium Resolution Infrared Radiometer
MSL	Meteorological Satellite Laboratory
MWS	Marine Weather Service
NADWARN	Nationwide Natural Disaster Warning
NAE	National Academy of Engineering
NAPCA	National Air Pollution Control Administration
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NAVAID	Navigation aid
NBS	National Bureau of Standards
NCAR	National Center for Atmospheric Research
NEIC	National Earthquake Information Center
NESC	National Environmental Satellite Center
NHC	National Hurricane Center
NHRL	National Hurricane Research Laboratory
NMC	National Meteorological Center
NODC	National Oceanographic Data Center
NOMSS	National Operational Meteorological Satellite System
NRC	National Research Council
NSF	National Science Foundation
NSSFC	National Severe Storms Forecast Center
NSSL	National Severe Storms Laboratory
NWRC	National Weather Records Center
ODESSA	Ocean Data Environmental Science Services Acquisition
OGO	Orbiting Geophysical Observatory
OPLE	Omega Position-Location Equipment
OSD	Office of Systems Development
OSV	Ocean Survey Vessels
PAGEOS	Passive Geodetic Explorer Satellite
PATWAS	Pilots Automatic Telephone Weather Answering Service
PCM	Pulse code modulation
PDM	Pulse duration modulation
PE	Primitive equation
Pibal	Pilot balloon
POL	Pacific Oceanographic Laboratories
PWS	Public Weather Service
RAMOS	Remote Automatic Meteorological Observing Station
RAREP	Radar Report
RAWARC	RAREP and Warning Coordination
RBC	Rotating-beam ceilometer
RCTM	Regional Center for Tropical Meteorology
R&D	Research and development
RDO	River District Office
RFC	River Forecast Center
RFF	Research Flight Facility
RL	Research Laboratories
RWC	Regional Weather Center
SAM	Subsynoptic advection model
SAWRS	Supplementary Aviation Weather Reporting Stations
SDFC	Space Disturbance Forecast Center
SDL	Space Disturbances Laboratory
SDO	Systems Development Office
SEAMAP	Scientific Exploration and Mapping
SELS	Severe Local Storms
SESAME	Systems Engineering Study of Atmospheric Measurements and Equipment
SID	Standard Instrument Departure
SID	Sudden ionospheric disturbances
SIDD	Scientific Information and Documentation Division
SIRS	Satellite Infrared Spectrometer
SMS	Synchronous Meteorological Satellite
SPDD	Systems, Plans, and Design Division
SSARR	Streamflow Synthesis and Reservoir Regulation
SSCC	Spin-scan cloud-camera
SST	Supersonic transport
STD	Salinity-temperature-depth
STRS	Satellite Time Recovery System
TDL	Techniques Development Laboratory
T&EL	Test and Evaluation Laboratory
TICUS	Tidal Current System
TIROS	Television Infrared Observation Satellite
TOS	TIROS Operational Satellite
TWEB	Transcribed Weather Broadcasts
UDC	Universal Decimal Classification
UHF	Ultrahigh frequency
UN	United Nations
UNESCO	United Nations Education, Scientific, and Cultural Organization
USATOPOCOM	U.S. Army Topographic Command
UT	Universal time
VFR	Visual Flight Rules
VHF	Very high frequency
VLF	Very low frequency
VTPR	Vertical Temperature Profile Radiometer
WB	Weather Bureau
WBFO	Weather Bureau Forecast Office
WBO	Weather Bureau Office
WBRT	Weather Bureau Radiotheodolite
WDC	World Data Center
WMC	World Meteorological Center
WMO	World Meteorological Organization
WPL	Wave Propagation Laboratory
XBT	Expendable Bathythermographs

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